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Statistical analysis for optical properties of irrigation water quality

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ABSTRACT

Depending on total suspended solids (TSS) concentration, suspended solids can easily clog small openings in a drip irrigation system. This problem is addressed through plugging, which falls into three categories, namely, slight, mild, and severe plugging (<50, 50–100, >100, respectively). Filtering is an important method for water irrigation designed to eliminate suspended solids, and the types and forms of filtering differ based on the purpose served by water use. Many remote and optical sensing techniques involving light interaction with a medium being investigated can detect TSSs in polluted water. Remote sensing applied to water substances is beneficial for monitoring water samples.

Keywords: Media filter; Water quality; Total suspended solid; Optics; Statistics analysis

1. Introduction and background

Total suspended solids (TSS) represent the actual content of mineral and organic particles transported in water. It is an essential measure of erosion linked to transporting nutrients, metals, and industrial and agricultural chemicals through river systems. Suspended sediment consists primarily of silt- and clay-size particles, which may be transported rapidly downstream to be deposited locally on floodplains and overbank storage locations or infiltrate into bed gravels [1]. The idea of remote sensing is to derive information on optical properties from variations in a water's color. It has been suggested that turbidity was only a relative measure with no environmental relevance unless calibrated against clarity or some other absolute optical quantity of suspended sediment concentration at each site of interest. Water clarity, a direct measure of the distance visible through the water, is also related to sediment in the water column. Visual water clarity describes the space that organisms can see underwater. Suspended and dissolved materials, correlations between optical water clarity and turbidity (NTU) affect water clarity, or TSS may vary dramatically between watersheds [2]. Doxaran et al. [3] determine water turbidity using visible and near-infrared

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(NIR) satellite data. Several studies document water absorption and dispersion coefficients – for example, the Ocean Optics Protocols [4]. Besides remote sensing, knowledge of in-water optical properties and processes is needed to estimate the light available for photosynthesis [5].

The optical properties of the material, especially TSS, vary substantially between regions; empirical "band-ratio" algorithms typically perform poorly in coastal waters where the material's optical properties differ from those used to develop the algorithm [6]. Many filtration systems do not remove clay and silt particles, or algae and bacteria, because they are too small [7]. TSS concentrations have also been studied in seawater using multispectral satellite data. Analyses have shown a non-linear correlation between TSS concentration and seawater reflectivity [8]. The sand filter achieved turbidity removal efficiency for the effluent between 61% and 71%. These turbidity removal efficiencies lowered the physical clogging risks and were similar to those observed with a sand media filter with effect sizes of 0.40 and 0.27 mm working with similar effluents [9]. Irrigation heads' partial and total clogging is closely related to irrigation water quality. It occurs for various reasons, including physical, biological, and chemical agents [10]. A hyperspectral sensor can be helpful for water quality monitoring in terms of both TSS and turbidity for sites with high turbidity levels and TSS concentrations. Traditional methods of river water monitoring are time-consuming, costly, and sometimes impractical to apply at a large scale. A better option can be to monitor river water characteristics using hyperspectral sensing techniques [11]. Elamin et al. [12] determined the hydraulic efficiency of a drip irrigation system using treated wastewater. Shaw et al. [13] decided on irrigation water quality, the clogging level over different operating periods, and the performance of varying clogging removal treatments to examine its impact on drip irrigation clogging.

The anti-clogging capability of the water drip unit decreased gradually when the operating pressure fell from 100 to 60 kPa but fell faster as the pressure dropped from 60 to 40 kPa or below. This variation in pressure, directly and indirectly, affects the formation of clogging impurities in the emitter [14]. The TSS value in the Alabaster Misr Bank water sample was less than that of Ward El-Nile Zaffaran at the same operating pressure [15]. A comprehensive review of case studies was conducted to review current knowledge concerning water treatment characteristics [16]. The optical properties of different TSS concentrations in media filters were studied using a He–Ne laser at 632.8 nm and selected transmission and absorption intensities of irrigation water samples when increasing TSS in the water sample occurs, filter pressure differential results, for this reason [17–19].

2. Method

2.1. Phase 1: experimental study

The study was executed in the agricultural engineering laser application laboratory at the National Institute of Laser Enhanced Science (NILES), Cairo University, Egypt. The equipment detects ultraviolet, visible, and infrared wavelengths to measure the absorption of irrigation water samples (optical) intensities. The spectrophotometer consisted of Ocean optics USB650, visible and invisible lights, holders, fiber optics, and a personal computer with spectra suite software. The experiments were carried out at the National Irrigation Laboratory of Agricultural Engineering Research Institute (AEnRI), ARC, Dokki, Giza, Egypt. These samples were available on the local market at a low cost using Local rock samples surveyed and collected from different locations in Egypt (Local basalt, Alabaster Misr Bank, and Ward El-Nile Zaffaran).

2.1.1. Filter system test – the irrigation system all filters under different pressures of 0.2, 0.4, 0.6 bar

In 2018 and 2019, local outcrops were surveyed, and samples were collected from different locations in Egypt. The filter unit comprises three 600 mm diameter cylindrical filters with 50 mm diameter inlets and outlets, as shown in Table 1 and Fig. 1, and water quality parameters for the SDI (surface drip irrigation system) (Evaluated in Faculty of Agriculture, Central Lab, Ain Shams University) as shown as Table 2. These samples were available on local market at a low cost without processing. Laboratory tests of local media samples treated with different water qualities of pure and Nile water and mechanical analysis of media properties samples, as shown in Table 3 and Fig. 2.

2.1.2. A light and spectrophotometer

The light spectrophotometer set up present study was executed in the laboratory of laser applications in agricultural engineering at the National Institute of Laser Enhanced Science (NILES), Cairo University. It detects suitable wavelengths from visible and invisible lights (ultraviolet, visual, and infrared) to measure the peak of optical properties at the reflection, transmission, and absorption by aribirty unit

Table 1
Specification of media filter types tested in the experiment

Filter type	Column diameter (mm)	Depth bed (mm)	Bed area material (m^2)	Max. flow (m^3/h)	Inlet/Outlet diameters (mm)
F – 1(B) F – 2(B.M.) F – 3(Z)	600	600	0.471	33.9	50

F – 1(B): Local basalt media.
F – 2(B.M.): Al-Abaster Misr Bank media.
F – 3(Z): Ward El-Nile Zaffaran media.

Fig. 1. Media filters.

Table 2
Water quality parameters for the SDI (surface drip irrigation system)

Parameter	Value
pH	6.90
EC (dS m^{-1})	0.41
Na^{+} (meq L^{-1})	1.50
K^{+} (meq L^{-1})	0.24
Ca^{+2} (meq L^{-1})	2.00
Mg^{+2} (meq L^{-1})	0.50
Cl^{-} (meq L^{-1})	2.40
CO_3^{-2} (meq L^{-1})	0.00
HCO_3^{-} (meq L^{-1})	1.30
SO_4^{-2} (meq L^{-1})	0.54
RSC	–1.20

(a.u.) intensities of irrigation water samples. The spectrophotometer consisted of Ocean optics USB650, visible and invisible lights, holders, fiber optics, and a personal computer with spectra suite software and its specifications, as shown in Table 4.

2.2. Phase 2: data collection

The SDI system's water quality parameters were evaluated in Tables 5–7.

2.3. Phase 3: statistical analysis

A descriptive statistical analysis was conducted using SPSS v. 25 to determine the relationship between the study variables. After data was collected from experimental studies, the data were analyzed further for dispersion analysis. The coefficient of variation is used to test the degree of dispersion to observe the distribution of survey data. The formula is:

$$CV = \frac{\sigma}{\bar{\bar{X}}}$$

Table 3
Mechanical analysis of SAMPLE media properties

Material size (mm)	Effective diameter (mm)		
	F – 1(B)	F – 2(B.M.)	F – 3(Z)
1.9	38	40	70.33
2.8	61.3	46	46

Fig. 2. Sieve (mechanical) analysis.

Table 4
Specifications of ocean optics USB 650 made in the USA

Specification	Value
Dimensions, mm	89.1 × 63.3 × 34.4
Focal length	42 mm input; 68 mm output
Detector range, nm	350–1,000
Stray light	0.05% at 600 nm; <0.10% at 435 nm
Fiber optic connector	SAM 905 to a single-strand optical fiber (0.22 N.A.)
Integration time	3.8 ms to 10 s (detector's limit is 15 s)
Operating systems	Windows 98/Me/2000/XP, Mac OS X, and Linux

$$\overline{X} = \frac{\sum_{i=1}^{N} x_i}{N}$$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} \left(x_i - \overline{X}\right)^2}{N}}$$

where CV is the coefficient of variation; σ is the standard deviation; x_i is the ith data point; $\overline{X}$ is the mean of all data points; N = the number of data points. Thus, the higher the CV, the higher the dispersion degree, and vice versa.

3. Results and discussion

3.1. Statistical analysis of TSS and wavelength for media types of filter

Table 8 shows the statistical analysis output for media types with TSS and wavelength. It can be deduced from the previous table the maximum mean of TSS was recorded for Ward El-Nile Zaffaran type (176.8 mg/L), while the minimum mean was recorded for Al-Abaster Misr Bank type (147.53 mg/L). Thus, the TSS values ranged from 102.4 to 293.0 mg/L for Ward El-Nile Zaffaran type with SD 101.9, 51.8 to 268.8 mg/L for Local basalt type with SD 109.1, and 57.6 to 270.0 mg/L for Al-Abaster Misr Bank type with SD 109.9 mg/L.

As shown in Table 9, it can be deduced the maximum mean of wavelength was recorded for Ward El-Nile Zaffaran type (371.7 nm), while the minimum mean was recorded for Al-Abaster Misr Bank type (357.7 nm). Thus, the wavelength v ranged from 370.0 to 373.0 nm for the Ward El-Nile Zaffaran type with SD 1.5, 351.0 to 365.0 nm for Local basalt type with S, and 351.0 to 365.0 nm for Al-Abaster Misr Bank type with SD 7.0 nm. From Table 10, it can be deduced that there was a significant effect (less than 0.05) of media type on the values of TSS for all water samples. From Table 11 it can be deduced that there was a significant

Table 5
Optical properties results of the first filter using local basalt media

P (bar)	TSS (mg/L)	Light wavelength (nm)	Absorption	Transmission	Reflection
			(Abs. a.u.)	(Trans. a.u.)	(Ref. a.u.)
0.2	51.8	354	0.151	58.547	95.672
0.2	51.8	356	0.096	54.22	84.009
0.2	51.8	359	0.216	90.194	82.061
0.2	51.8	360	0.329	94.459	66.393
0.2	51.8	361	0.138	93.884	83.793
0.2	51.8	368	0.267	71.494	55.435
0.2	51.8	371	0.242	100.723	88.721
0.2	51.8	376	0.127	90.066	64.939
0.2	51.8	378	0.118	77.311	99.481
0.2	51.8	396	0.214	61.682	62.383
0.4	115	350	0.317	57.202	52.41
0.4	115	351	0.382	36.869	52.245
0.4	115	354	0.251	55.806	47.068
0.4	115	355	0.37	41.909	56.935
0.4	115	372	0.283	51.245	49.643
0.4	115	373	0.278	54.139	50.016
0.4	115	374	0.285	51.909	52.142
0.4	115	376	0.313	51.876	49.417
0.4	115	378	0.282	50.547	50.77
0.4	115	380	0.289	52.908	49.286
0.6	268.8	350	0.127	40.692	17.224
0.6	268.8	351	0.285	70.859	56.931
0.6	268.8	352	0.521	13.365	26.762
0.6	268.8	359	0.298	60.631	39.67
0.6	268.8	360	0.777	55.991	16.28
0.6	268.8	361	0.449	40.815	40.513
0.6	268.8	364	0.492	43.257	43.139
0.6	268.8	365	1.127	21.288	67.089
0.6	268.8	389	0.191	65.53	64.348
0.6	268.8	395	0.206	68.627	75.161

Table 6
Optical properties of water from the second filter: using Al-Abaster Misr Bank media

P (bar)	TSS (mg/L)	Light wavelength, (nm)	Absorption	Transmission	Reflection
			(Abs. a.u.)	(Trans. a.u.)	(Ref. a.u.)
0.2	57.6	357	0.236	51.136	74.93
0.2	57.6	359	0.251	150.465	76.671
0.2	57.6	365	0.263	123.754	124.24
0.2	57.6	366	0.17	70.795	69.275
0.2	57.6	373	0.185	83.882	95.835
0.2	57.6	377	0.176	86.807	71.672
0.2	57.6	408	0.195	63.183	63.499
0.2	57.6	412	0.196	64.517	66.001
0.2	57.6	414	0.199	62.54	63.196
0.2	57.6	416	0.193	64.594	64.756
0.2	57.6	422	0.187	66.68	66.451
0.4	135	350	0.25	62.827	51.844
0.4	135	351	0.367	52.69	42.122
0.4	135	357	0.242	64.255	64.464
0.4	135	359	0.303	48.426	53.577
0.4	135	360	0.268	63.008	49.158
0.4	135	361	0.33	47.155	50.895
0.4	135	374	0.333	45.988	44.227
0.4	135	376	0.341	47.008	41.785
0.4	135	379	0.323	48.307	44.369
0.4	135	380	0.353	43.81	41.989
0.4	135	382	0.326	46.634	45.635
0.6	270	355	0.895	30.132	7.305
0.6	270	357	0.978	24.262	25.182
0.6	270	365	0.506	32.861	15.921
0.6	270	366	0.294	63.693	53.506
0.6	270	372	0.487	32.094	66.587
0.6	270	373	0.455	31.061	41.818
0.6	270	376	0.302	50.987	48.543
0.6	270	377	0.416	22.556	46.622
0.6	270	378	0.386	28.882	40.594
0.6	270	382	0.484	46.255	40.642

effect (less than 0.05) of media type on the wavelength values for all water samples.

3.2. Statistical analysis of TSS and wavelength for pressure difference of filter

Table 12 shows the statistical analysis output for pressure difference with TSS and wavelength. It can be deduced the maximum mean of TSS was recorded for 0.6 bar (277.3 mg/L), while the minimum mean was recorded for 0.2 bar (70.6 mg/L). The TSS values were ranged from 51.8 to 102.4 mg/L for 0.2 bar with SD 27.7, 115.0 to 140.0 mg/L for 0.4 bar with SD 13.2, and 268.8 to 293.0 mg/L for 0.6 bar with SD 13.6 mg/L. In Table 13, it can be deduced the maximum mean of wavelength was recorded for 0.2 and 0.6 bar (365.0 nm), while the minimum mean was recorded for 0.4 bar (358.0 nm). The wavelength values ranged from 360.0 to 370.0 nm for 0.2 bar with SD 5.0, 351.0 to 372.0 nm for 0.4 bar with SD 12.1, and 357.0 to 373.0 nm for 0.6 bar with SD 8.0 nm for. From Table 14, it can be deduced that there was a significant effect (less than 0.05) of pressure difference on TSS values for all water samples. From Table 15 it can be deduced that there was no significant effect (more than 0.05) of media type on the wavelength values for all water samples.

3.3. Paired-samples T-test of TSS and wavelength

Paired-samples T-test was done to compare the means of TSS and wavelength for water samples to obtain how they indicate one another, which clarifies the potential to use optical properties to measure the TSS of water samples. Table 16 shows the statistical analysis output for pressure difference with TSS and wavelength. The table

Table 7
Optical properties of water from the third filter: using Ward El-Nile Zaffaran media

P (bar)	TSS (mg/L)	Light wavelength, (nm)	Absorption (Abs. a.u.)	Transmission (Trans. a.u.)	Reflection (Ref. a.u.)
0.2	102.4	357	0.164	66.814	69.502
0.2	102.4	370	0.32	91.725	71.864
0.2	102.4	375	0.266	87.586	90.427
0.2	102.4	377	0.265	77.899	82.244
0.2	102.4	392	0.167	68.6	64.741
0.2	102.4	396	0.272	60.853	56.631
0.2	102.4	405	0.176	62.436	61.567
0.2	102.4	408	0.169	61.19	60.635
0.2	102.4	415	0.268	63.971	62.235
0.2	102.4	416	0.17	62.679	60.372
0.2	102.4	418	0.223	62.361	60.804
0.4	140	371	0.296	54.19	49.367
0.4	140	372	0.355	49.592	54.422
0.4	140	373	0.322	50.041	55.259
0.4	140	374	0.297	48.628	51.862
0.4	140	375	0.336	51.457	52.409
0.4	140	378	0.294	50.125	48.927
0.4	140	380	0.326	48.207	47.624
0.4	140	381	0.317	51.866	50.4
0.4	140	382	0.307	52.138	50.248
0.4	140	384	0.283	53.706	50.926
0.6	293	354	0.755	31.441	32.32
0.6	293	355	0.226	11.221	19.951
0.6	293	363	0.934	35.613	34.639
0.6	293	366	1.044	33.227	62.571
0.6	293	370	0.751	9.598	19.677
0.6	293	371	0.696	33.57	24.376
0.6	293	372	0.722	19.358	22.74
0.6	293	373	1.4	20.137	12.546
0.6	293	375	1.053	42.139	19.09
0.6	293	380	0.565	30.06	25.808

Table 8
Descriptive analysis of TSS with the deferent types of media of the filter

Media type		Local basalt	Al-Abaster Misr Bank	Ward El-Nile Zaffaran	Total
N		3	3	3	9
Mean		153.5333	147.5333	176.8000	159.2889
Std. deviation		109.13117	109.87381	101.94371	93.66339
Std. error		63.00691	63.43567	58.85723	31.22113
Maximum		268.80	270.00	293.00	293.00
Minimum		51.80	57.60	102.40	51.80
95% confidence	Upper bound	424.6302	420.4750	430.0422	231.2849
interval for mean	Lower bound	–117.5635	–125.4083	–76.4422	87.2928

showed the relationship between differential pressure and reflection, transmission, and absorption intensities for a water sample when increasing TSS in the water sample leads to filter pressure differential results. For this reason, the difference pressure was increased from 0.2 bar until it reached 0.6 bar. Also, results for that exchange in different pressure for reflection, transmission, and absorption at the same range wavelength were changed. Thus, it can be

Table 9
Descriptive analysis of wavelength with the different types of media of the filter

ΔP		0.2 bar	0.4 bar	0.6 bar	Total
N		3	3	3	9
Mean		70.6	130	277.2667	159.2889
Std. deviation		27.69188	13.22876	13.63867	93.66339
Std. error		15.98791	7.63763	7.87429	31.22113
Maximum		102.4	140	293	293
Minimum		51.8	115	268.8	51.8
95% confidence	Upper bound	139.3904	162.8621	311.147	231.2849
interval for mean	Lower bound	1.8096	97.1379	243.3863	87.2928

Table 10
Analysis of variance (ANOVA) for TSS with the different types of media of the filter

Compare	Sum of squares	df	Mean square	F	Sig.
Between groups	1,433.876	2	716.938	0.063	0.040
Within groups	68,748.773	6	11,458.129		
Total	70,182.649	8			

Table 11
Analysis of variance (ANOVA) for wavelength with the deferent type of media of the filter

Compare	Sum of squares	df	Mean square	F	Sig.
Between groups	366.000	2	183.000	5.382	0.046
Within groups	204.000	6	34.000		
Total	570.000	8			

Table 12
Descriptive analysis of TSS with a pressure difference of filter

ΔP		0.2 bar	0.4 bar	0.6 bar	Total
N		3	3	3	9
Mean		70.6	130	277.2667	159.2889
Std. deviation		27.69188	13.22876	13.63867	93.66339
Std. error		15.98791	7.63763	7.87429	31.22113
Maximum		102.4	140	293	293
Minimum		51.8	115	268.8	51.8
95% confidence	Upper bound	139.3904	162.8621	311.147	231.2849
interval for mean	Lower bound	1.8096	97.1379	243.3863	87.2928

Table 13
Descriptive analysis of wavelength with a pressure difference of filter

ΔP		0.2 bar	0.4 bar	0.6 bar	Total
N		3	3	3	9
Mean		365	358	365	362.6667
Std. deviation		5	12.12436	8	8.44097
Std. error		2.88675	7	4.6188	2.81366
Maximum		370	372	373	373
Minimum		360	351	357	351
95% confidence interval	Upper bound	377.4207	388.1186	384.873	369.155
for mean	Lower bound	352.5793	388.1186	384.873	369.155

Table 14
Analysis of variance (ANOVA) for TSS with a pressure difference of filter

Compare	Sum of squares	df	Mean square	*F*	Sig.
Between groups	67,926.942	2	33,963.471	90.340	0.000
Within groups	2,255.707	6	375.951		
Total	70,182.649	8			

Table 15
Analysis of variance (ANOVA) for wavelength with a pressure difference of filter

Compare	Sum of squares	df	Mean square	*F*	Sig.
Between groups	98.000	2	49.000	0.623	0.568
Within groups	472.000	6	78.667		
Total	570.000	8			

Table 16
Output of statistical analysis for pressure difference with TSS and wavelength

Paired differences		Pair 1 TSS – wavelength
Mean		–203.37778
Std. deviation		92.49224
Std. error mean		30.83075
95% confidence interval	Lower	–274.47361
of the difference	Upper	–132.28195
t		–6.597
df		8
Sig. (2-tailed)		0

deduced that there was a significant value of T (less than 0.05), which approved an indication of wavelength for values of TSS for all water samples.

4. Conclusion

Statistical methods are important in water quality analysis because much of what is known about water quality comes from numerical datasets. This study conducted statistical analysis to measure the peaks of optical properties at the reflection, transmission, and absorption intensities of irrigation water samples. The water quality data from an experiment based on the measurements consisted of remote sensing reflectance spectra from radiance and irradiance measurements performed using Ocean Optics. This tool can detect sufficient wavelengths from visible and invisible light (ultraviolet, visual, and infrared). The correlations found were significant at the 0.01 and 0.05 levels. A descriptive statistical analysis was then carried out using the Statistical Package for the Social Sciences (v. 25). The findings showed that using a media filter made of local basalt, Al-Abaster Misr Bank, and Ward El-Nile Zaffaran media increased TSS in a water sample and generated differential results on filter pressure. Such pressure increased from 0.2 to 0.6 bar, causing increased absorption but reduced reflection and transmission.

- Statistical analysis of TSS and wavelength for media types of filter

The ANOVA showed significant effects (less than 0.05) of media type on TSS concentration and wavelength in all the water samples.

- Statistical analysis of TSS and wavelength for pressure difference of filter

The ANOVA indicated a significant effect (less than 0.05) of pressure difference on TSS concentration and wavelength in all the water samples.

Conflict of interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Data availability statement

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

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