Quality Determination for Drinking Water by Using Image Quality Assessment

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KEYWORDS

Full-reference image quality measure, NK, SC, water quality.

ABSTRACT

Without human involvement, the need for an automatic algorithms for quality assessment takes place especially for the case of distinguishing the quality of drinking water when the latter has the same color. Image quality assessment is closely related to image similarity assessment in which quality is based on the differences between a degraded image and the unmodified image. Based on a design of a full reference image quality measure with the help of an assumption that one of the captured images can be modeled to be the original one. The similarity measure can serve then as a quantitative measurement of the quality of the second image. A comparison between images has been tested and then analyzed by using laboratory investigations first and then by image quality metrics. Images have been captured by adopting a designing system prepared for this purpose. Results show that difference in water turbidity, heating process, and magnetization affect strongly upon image›s band histogram during the comparison that has been made here between drinking water samples. Among the various metrics that have been used here, the results show that Normalized Cross-Correlation (NK) and Structural Content (SC) are the best used measures in the presented assumption.

تحديد جودة مياه الشرب بأستخدام مؤشرات تقييم كفاءة الصورة

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الكلمات الدالة

المقياس المرجعي الكامل لجودة الصورة ، NK, SC ، جودة المياه .

المُستلخص

من دون تدخل للأنسان يذكر أصبحت الحاجة الى الخوارزميات الأتوماتيكية لتقييم الجودة تحتل مركزا» مهما» لتمييز كفاءة مياه الشرب وخصوصا» عندما تمتلك المياه اللون نفسه. ان تقييم جودة الصورة يرتبط ارتباطا» وثيقا» بتقييم تشابه الصورة والتي تستند الجودة فيها على الأختلافات بين الصورة المشوهة والصورة الغير معدلة (الصورة الأصلية). بالأستناد الى المقياس المرجعي الكامل لجودة الصورة وبمساعدة الفرضية المعتمدة في البحث الحالي بأعتبار احدى الصور الملتقطة هي الصورة الأصلية، ومن ثم فأن مقياس التشابه يمكن ان يختبر كمقياس كمي لجودة الصورة الثانية. تم اجراء مقارنة بين الصور ومن ثم تحليلها بالأعتماد على الفحوص المختبرية أولا» ومن ثم بواسطة مقاييس جودة الصورة. تم التقاط الصور من خلال اعتماد نظام صمم لهذا الغرض. من خلال اجراء المقارنة بين عينات مياه الشرب المستخدمة اشارت النتائج الى ان الفرق في عكرة الماء، عملية التسخين، والمغنطة تؤثر وبقوة على المخطط التكراري لحزمة الصورة الملتقطة. بينت النتائج ومن بين مختلف المقاييس المعتمدة في البحث ان مؤشري الأرتباط-المتقاطع المعير والمحتوى التركيبي هما أفضل المقاييس والتي تم أستخدامها في الفرضية المقترحه في البحث.

Introduction

In recent years, attention has been focused on the local environmental problems such as noises, red tides, air pollution and water clarity which obstructed the comfortable human lives [1]. Water quality plays an important role for food safety particularly for infants [2]. Many authors focuses their attention toward this topic. (Aish, 2013) for example investigated drinking water contamination in the middle area of the Gaza strip. Samples were taken from different sources and the results of the chemical and bacteriological parameters had been compared with that of the Word Health Organization (WHO) and Palestinian Water Authority (PWA) [3]. Others presented by (Kulkarni, 2011) has been utilized TM imagery for water quality purposes in East Texas. He developed several regression models to evaluate correlation between water quality parameters and spectral reflectance values [4].

In spite the considerations of the human visual system (HVS) as being a tool to extract structural information from the viewing field [5], the need for an automatic algorithms for drinking water quality assessment arises especially when the later (i.e. drinking water) has the same color [1]. So, the assessment for image quality is a traditional need [6]. Image quality assessment means estimating the quality of an image and it is used for many image processing applications such as acquisition, compression, restoration, enhancement and other applications [7,8].

Image quality methods can be categorized into two parts; subjective and objective. Subjective evaluations are expensive, time-consuming and it is impossible to implement them into automatic real-time systems while objective evaluations are automatic and mathematical defined algorithms [5,7]. Due to these reasons, an attention toward an objective image quality assessment methods has been focused in this paper.

Objective Image Quality Assessment

The dependence on the availability of a "perfect quality" reference image, methods for an objective image quality can be classified into:

(i) Full-Reference (FR): Meaning that a complete reference image is assumed to be known.

(ii) No-Reference (NR): The reference image is not available, and a no-reference or "blind" quality assessment approach is desirable.

(iii) Reduced-Reference (RR): The reference image is partially available here in the form of a set of extracted features made available as side information to help evaluate the quality of the distorted image [5,8,9].

The presented work here has been established upon the assumption of a full-reference image quality measure. There are two general classes of objective quality assessment approaches [5,9]:

- Simple correlation based metrics
- HVS feature based metrics

There are a lot of metrics of image quality. The adopted measures can be listed as follows:

1. Simple Correlation Based Metrics

1.1. Normalized Cross-Correlation (*NK*):

The similarity between two digital images can be quantified in terms of correlation function. Normalized Cross-Correlation (*NK*) measures the closeness between two images and is given by [5]:

$$NK = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(x(i,j).y(i,j))}{\sum_{i=1}^{M}\sum_{j=1}^{N}(x(i,j))^2} \quad \text{.....................................(1)}$$

Where $x(i,j)$ and $y(i,j)$ represents the reference and the distorted image respectively. Pixel position of the MxN image is i and j respectively.

1.2. Structural Content (*SC*)

This approach measures the similarity also between images which is given by the next equation [5]:

$$SC = \frac{\sum_{i=1}^{M}\sum_{j=1}^{N}(y(i,j))^2}{\sum_{i=1}^{M}\sum_{j=1}^{N}(x(i,j))^2} \quad \text{...(2)}$$

2. HVS Feature Based Metrics

2.1. Structural Similarity Index Metric (*SSIM*)

This measure compares two images using information about luminous, contrast and structure as follow [8,10,11]:

$$l(x,y)=\frac{2\mu_x(x,y)\mu_y(x,y)+C_1}{\mu_x^2(x,y)+\mu_y^2(x,y)+C_1}\text{.................................}(3)$$

$$c(x,y)=\frac{2\sigma_x(x,y)\sigma_y(x,y)+C_2}{\sigma_x^2(x,y)+\sigma_y^2(x,y)+C_2}\text{................................}(4)$$

$$s(x,y)=\frac{\sigma_{xy}(x,y)+C_3}{\sigma_x(x,y)\sigma_y(x,y)+C_3}\text{.....................................}(5)$$

Where x and y are two different blocks in two separate images, μ_x, σ_x and σ_{xy} are the average of x, standard deviation of x, and the covariance of x and y respectively where [5,8]:

$$\mu_x(x,y)=\sum_{p=-P}^{P}\sum_{q=-Q}^{Q}w(p,q)x(x+p,y+q)\text{..}(6)$$

$$\sigma_x^2(x,y)=\sum_{p=-P}^{P}\sum_{q=-Q}^{Q}w(p,q)[x(x+p,y+q)-\mu_x(x,y)]^2\text{.........................}(7)$$

$$\sigma_{xy}(x,y)=\sum_{p=-P}^{P}\sum_{q=-Q}^{Q}w(p,q)[x(x+p,y+q)-\mu_x(x,y)][y(x+p,y+q)-\mu_y(x,y)]\text{.............}(8)$$

Where $w(p,q)$ is a Gaussian weighting function such that:

$$\sum_{p=-P}^{P}\sum_{q=-Q}^{Q}w(p,q)=1\text{...}(9)$$

And C_1, C_2 and C_3 are constants given by [8,11]:

$C_1=(K_1L)^2$…………………………(10)

$C_2=(K_2L)^2$………………………..(11) and

$C_3=C_2/2$…………………… ……..(12)

L is the dynamic range for the sample data, i.e. L=255 for 8 bit content and $K_1<<1$ and $K_2<<1$ are two scalar constants. Throughout this research a value of 0.01 and 0.03 are set to parameter K_1 and K_2 respectively [8,11]. The structure similarity can be written as [8,9,10,11]:

$$SSIM(x,y)=[l(x,y)].[c(x,y)].[s(x,y)]\text{................................}(13)$$

2.2. *MSSIM*

The mean of *SSIM* is denoted *MSSIM* and is given as [5,9,10]:

$$MSSIM(x,y)=\frac{1}{M}\sum_{j=1}^{M}SSIM(x_j,y_j)\text{................................}(14)$$

where M is the total no. of windows over the image, x_j and y_j are image's content at the jth local window.

2.3. *DSSIM*

This is the structural dissimilarity metric which is derived from *SSIM* as follows [9]:

$$DSSIM(x,y)=\frac{1}{1-SSIM(x,y)}\text{.......................................}(15)$$

3. Water Quality

The quality of water varies with the source. It may be or not contain dissolved minerals, dissolved gases, organic matter, microorganisms, or combinations of these impurities that cause deterioration of metalworking fluid performance [12]. It is not correct to assume that clear water is always healthy. Slightly turbid water for an example can be perfectly healthy, while clear water could contain unseen toxins or unhealthy levels of nutrients [13]. A description for the selected properties for water-quality criteria is explained in Table (1)

Table (1) Water-quality criteria, standards, or recommended limits for selected properties and constituents

[All standards are from U.S. Environmental Protection Agency (1994a) unless noted. MCL, Maximum Contaminant Level; SMCL, Secondary Maximum Contaminant Level; mg/L, milligrams per liter; --, no limit established][14]

Constituent or property	Standard	Significance
Nitrate (NO_3)	10 mg/L MCL	Nitrate is naturally occurring ions that are part of the nitrogen cycle. The nitrate ion (NO_3^-) is the stable form of combined nitrogen for oxygenated systems [14,15].
pH	6.5-8.5 units SMCL	It is an expression which indicates whether a substance is acidic, neutral, or alkaline[12,14].
Total Dissolved Solids (TDS)	500 mg/L SMCL	It stands for total dissolved solids and represents the total concentration of dissolved substances in water. TDS is made up of inorganic salts, as well as a small amount of organic matter [14,16].
Electrical Conductivity (EC)	--	A measure of the ability of water to conduct an electrical current; varies with temperature. Values are reported in microsiemens per centimeter at 25° Celsius [14].
Dissolved Oxygen (DO)	--	It presents in surface water in dissolved form with variable percentage depending upon the temperature of water and other solid contents in water [17].
Free Chlorine Measuring System (FCL)	--	It is presented in most disinfected drinking-water at concentrations 0.2-1 mg/L [18].
TURBIDITY	--	It is caused by particles suspended or dissolved in water that scatter light making the water appear cloudy or murky. Particulate matter can include sediment-especially clay and silt, fine organic and inorganic matter, soluble colored organic compounds, algae, and other microscopic organisms. It›s unit is called a Nephelometric Turbidity Unit (NTU). Turbidity is a general measure of the scattering and absorbing effect that suspended particles have on light. The standard for drinking water is 0.5-1.0 NTU [13,19].

Experimental Results

1. Laboratory Investigations

From different sources, samples of drinking water have been collected and carried out within 24 hours. The source for each sample can be summarized in the next table.

Table (2) Drinking water samples with their description

Sample Sequence	**Water Source**	**Description**
1	Zamzum water	It has a wonderful physique that makes it different from other drinkable liquids because it is naturally pure and sterile that has no germs in it [2]
2	House water tank	Tap water inside an aluminum tank which is located at house›s roof
3	Ozonated water	Healthy water sterile by ozone and ultraviolet radiation.
4	Tap water	Tap water in the Karkh district of Baghdad
5	Ozonated Magnetic water	The ozonated water was magnetized by using two different magnet poles which affixed to the exterior surface of the incoming water pipe.
6	Boiled tap water	Tap water was boiled to the boiling point

The previous samples have been examined at Environment and Water Researches and Technology Directorate/ Ministry of Science & Technology. Table (3) shows the results for this examination.

Table (3) Laboratory investigations at Environment and Water Researches and Technology Directorate/ Ministry of Science & Technology

Sample Sequence	Source of Drinking Water	NO_3 ppm	pH	TDS mg/L	EC ms/cm	DO mg/L	FCL mg/L	TURB NTU
1	Zamzum water	4.291	8.08	328	658	5.35	0.04	1.05
2	House water tank	1.055	7.6	243	486	5.43	0.01	3.02
3	Ozonated water	0.653	7.3	41	82.3	5.23	0.01	0.95
4	Tap water	1.189	7.58	216	436	5.15	0.03	2.41
5	Ozonated Magnetic water	0.589	7.45	41	82.3	4.79	0.02	1.02
6	Boiled tap water	1.006	7.9	211	421	4.63	0.00	2.03

2. Image Quality Assessment Results

2.1. Acquisition System

Images have been captured by using a designing system shown in Fig.(1) which is prepared for this purpose.

The system consists of a full spiral saving energy lamp (economic), test tube filling with the selected water and a Sony Cyber-shot DSC-W710 camera of 5x optical zoom and 16.1 Mega pixels.

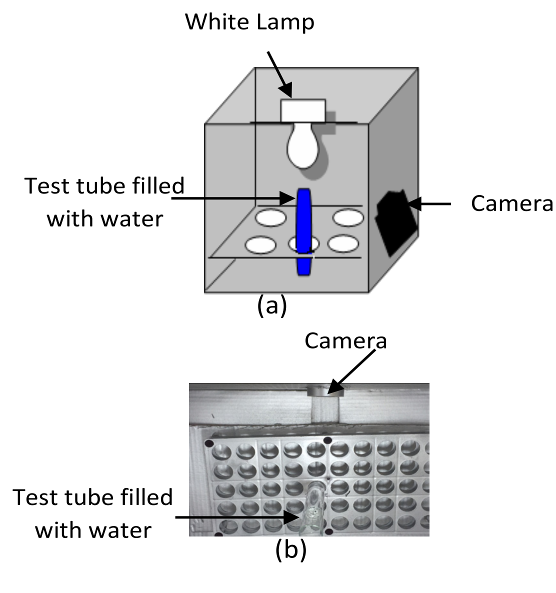

Fig. (1) The acquisition designing system
(a) General overview **(b)** A close look inside the system

2.2. Analyzing Results and Discussions

The analysis process takes place when a histogram for a three blocks of sizes (10x10) has been drawn. These blocks were extracted randomly for every captured image. Figure (2) shows the fitting lines to the histograms for all comparisons that have been done here. Due to the very week combination absorptions at the low-energy end of the visible spectrum (i.e. red), one can noticed that R-band progresses first followed by green band and then by the blue band at the last. This reason explains the pale blue color for the pure water.

In general, all bands' curves lie in the range of gray level between 80-150 except for the case for tap water, boiled tap water and house water tank as shown in Figs.(2e, f & h) respectively. Heating process and its effect upon images' bands was obviously noticed through the existence of two peaks instead of one peak as in Figs. (2f &h). Difference in turbidity affects upon drinking water histograms through the comparing process between the two samples. The turbidity test shows a very close value with a difference 0.03NTU between zamzam water and ozonated magnetized water as in Figs. (2a & b) respectively. As a result, a similar behavior appeared significantly in their histograms.

The effect of magnetization appeared also by comparing ozonated water and ozonated magnetized water as in Figs.(2c &d) respectively. In such comparison, a turbidity has a close difference value equal to 0.07NTU, while the difference value for turbidity that results from the comparison case between tap water and boiled tap water as in Figs. (2e & f) respectively reaching a value equal to 0.38NTU. This explains the dissimilarity between their histograms. The greatest difference value for turbidity occurs for the comparison case between tap water and house water tank as in Figs.(2g & h) respectively reaching a value equal to 0.61NTU which is also appeared in their different curves.

2.3. Results and Discussions

For image assessment, different objective image quality metrics have been tested (i.e. *SSIM*, *DSSIM*, *MSSIM*, *NK*, *SC*) upon a block of size (15x30) for all captured images. A hypothesis has been supposed. The assumption is that one of the two images was considered to be the perfect quality one, then the similarity measure can serve as a quantitative measurement of the quality of the second image. So, the reference and the distorted images have been tested through the use of the adopted metrics letting the metric decide which of them is the reference and which is the distorted one by using two attempts for their applications. Table (4) & (5) explain the results. From the results, one can automatically predict image quality by noticing the values. It seems that *SSIM*, *DSSIM*, and *MSSIM* didn't give any opinion about the reference and distorted images. Due to their expressions, *NK* and *SC* gave the evidence in determining the essence of the reference and distorted images. The shaded blocks in these tables determine the final results for the assumption that has been supposed here which can be summarized in Table(6).

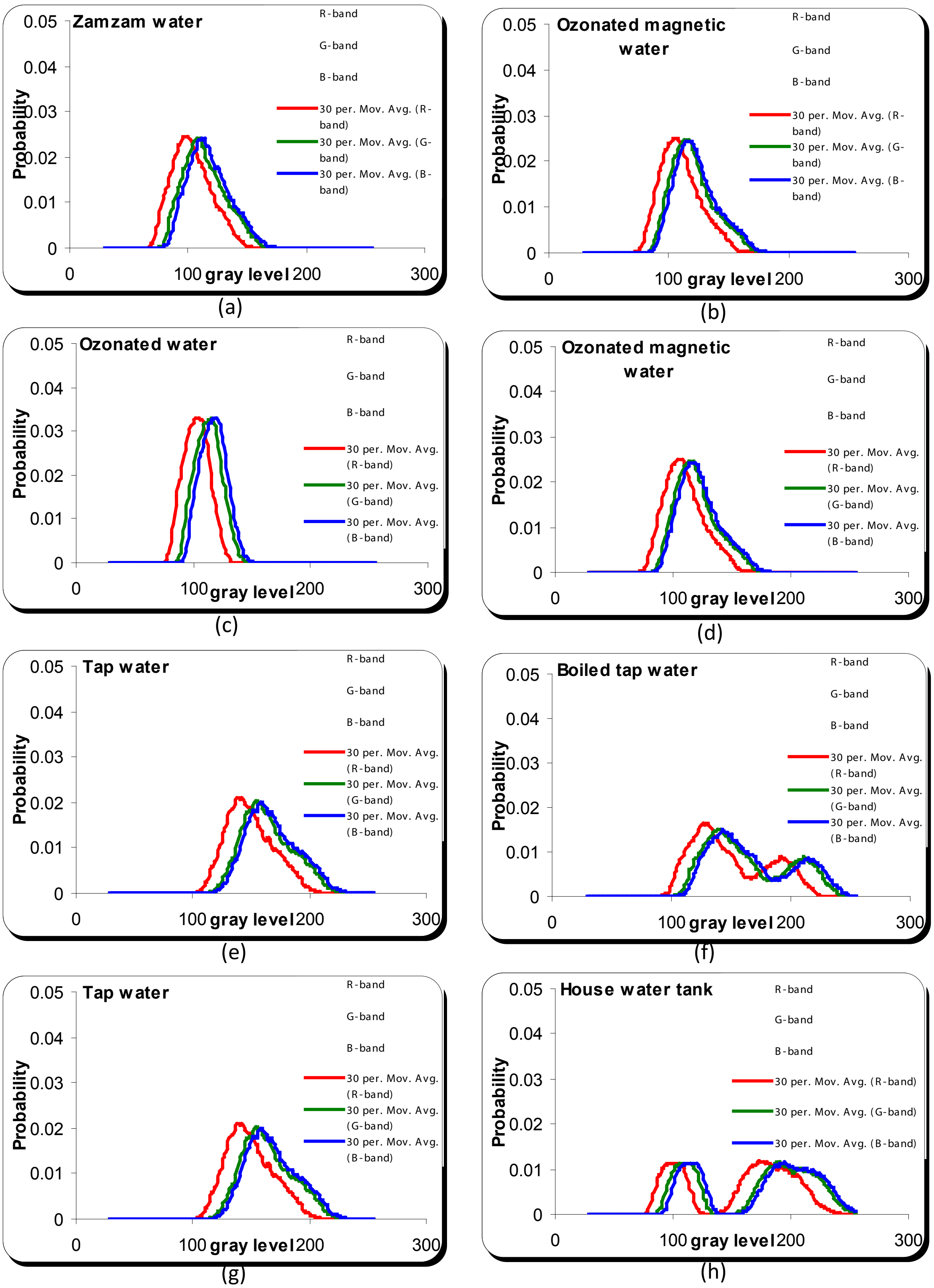

Fig.(2) **Fitting line results of histograms for each image's band**

Table (4) Image quality assessment results (1st attempt)

Images to be tested	Band type	*SSIM*	*DSSIM*	*MSSIM*	*NK*	*SC*
Original: Zamzum water **Distorted:** Ozonated Magnetic water	**R**	0.8312	5.9263	0.8866	1.4213	2.0371
	G	0.8469	6.5319	0.8978	1.3930	1.9562
	B	0.8487	6.6135	0.9040	1.3783	1.9152
Original: Ozonated water **Distorted:** Ozonated Magnetic water	**R**	0.7921	4.8114	0.8458	1.5224	2.3376
	G	0.8016	5.0427	0.8563	1.4974	2.2600
	B	0.8111	5.2943	0.8692	1.4677	2.1722
Original: Tap water **Distorted:** Boiled tap water	**R**	0.9906	107.263	0.9622	1.2099	1.4755
	G	0.9925	134.875	0.9652	1.1993	1.4489
	B	0.9926	135.782	0.9657	1.1980	1.4453
Original: House water tank **Distorted:** Tap water	**R**	0.9759	41.6396	0.9460	0.7892	0.6272
	G	0.9809	52.5072	0.9528	0.8028	0.6485
	B	0.9809	52.3692	0.9546	0.8065	0.6543

Table (5) Image quality assessment results (2nd attempt)

Images to be tested	Band type	*SSIM*	*DSSIM*	*MSSIM*	*NK*	*SC*
Original: Ozonated Magnetic water **Distorted:** Zamzum water	**R**	0.8312	5.9263	0.8866	0.6977	0.4908
	G	0.8469	6.5319	0.8978	0.7121	0.5111
	B	0.8487	6.6135	0.9040	0.7196	0.5221
Original: Ozonated Magnetic water **Distorted:** Ozonated water	**R**	0.7921	4.8114	0.8458	0.6512	0.4277
	G	0.8016	5.0427	0.8563	0.6625	0.4424
	B	0.8111	5.2943	0.8692	0.6756	0.4603
Original: Boiled tap water **Distorted:** Tap water	**R**	0.9906	107.263	0.9622	0.8200	0.6777
	G	0.9925	134.875	0.9652	0.8277	0.6901
	B	0.9926	135.782	0.9657	0.8288	0.6918
Original: Tap water **Distorted:** House water tank	**R**	0.9759	41.6396	0.9460	1.2584	1.5943
	G	0.9809	52.5072	0.9528	1.2379	1.5419
	B	0.9809	52.3692	0.9546	1.2326	1.5282

Table (6) Final results for image quality assessment assumption

Reference Image	Distorted Image
Ozonated Magnetic water	Zamzam water
Ozonated Magnetic water	Ozonated water
Boiled tap water	Tap water
House water tank	Tap water

Conclusion

For the design of image quality measures, the use of structural similarity has been proposed based on the assumption that one of the images can be modeled to be the reference image, then the similarity measure can serve as a quantitative measurement of the quality of the second one. Results show that *NK* and *SC* measures are best performance than the rest used estimators in determining which the original and which is the distorted one. Among all the investigations that have been tested in the laboratory, image processing results showed that the difference in turbidity, heating process and magnetization affect strongly upon bands' histograms for all the captured images.

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Nomenclature

C_1, C_2, C_3	constants
DO	Dissolved Oxygen
DSSIM	Structural Dissimilarity
EC	Electrical Conductivity
FCL	Free Chlorine Measuring System
FR	Full-Reference method
HVS	Human Visual System
K_1, K_2	Scalar constants
L	Dynamic range of the image
M	Total no. of windows over the image
MCL	Maximum Contaminant Level
MSSIM	Mean of Structural Similarity Index Metric
NTU	Nephelometric Turbidity Unit
NK	Normalized Cross-Correlation
NO_3	Nitrate
NR	No-Reference method
PWA	Palestinian Water Authority
RR	Reduced-Reference method
SC	Structural Content
SMCL	Secondary Maximum Contaminant Level
SSIM	Structural Similarity Index Metric
TDS	Total Dissolved Solids
WHO	Word Health Organization
$c(x,y)$	contrast
i, j	pixel position of MxN image respectively
$l(x,y)$	luminous
mg/L	milligrams per liter
$s(x,y)$	structure
$w(p,q)$	Gaussian weighting function
$x(i,j)$	reference image
x, y	two different blocks in two separate images
x_j, y_j	image›s content at the j^{th} local window
$y(i,j)$	distorted image
σ_x	Standard deviation of x
σ_{xy}	covariance of x and y
μ_x	average of x
--	no limit established