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From Knowledge to Wisdom

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Effect of Brine Disposal on Seawater Quality at Az-Zour Desalination Plant in Kuwait: Physical and Chemical Properties

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Abstract: Seawater desalination has become the only viable source of fresh water for Kuwait. However, desalination plants could have several impacts on the surrounding marine environment. The major concern of these impacts surrounds the outfall effluent discharge because of its physical and chemical features including high temperature and salinity associated with residual chemicals used in the pretreatment process. In this study assessment of potential impact of Az-Zour desalination plant discharge effluent on marine environment was carried out. The assessment consisted of field measurements and numerical modelling of effluent dispersion. The results revealed a potential impact by temperature and salinity between 4 and 6 °C and 2-4 ppt above ambient and mean levels for Kuwait seawater. The predictions of hydrodynamic modelling show that the plume from the outfall runs parallel to the shoreline and the influenced area can reach to about 40 km^2.

Key words: Desalination, impact, seawater, assessment.

1. Introduction

Most of the arid and semi-arid countries suffer from the scarcity of water resources and this is considered as the major challenge that has to be faced. Severe water shortages can lead to the deterioration of a person's health and may severely constrain the development of the community. These countries have turned to desalination of seawater as a solution to this growing problem [1]. Desalination is the process by which freshwater is extracted from saline waters, such as seawater and brackish water. Commercially available desalination techniques are categorized either as distillation-based or as membrane-based technologies. Distillation-based processes are MSF (Multi Stage Flash), MED (Multiple Effect Distillation), and VC (Vapor Compression). Main membrane-based processes are Reverse Osmosis (RO). Distillation-based processes involve phase changes. In Kuwait, water resources are very limited and most of the fresh water is produced by desalting Gulf seawater. During the last five decades, Kuwait has developed six MSF dual-purpose plants for water production and power generation, along a 120-km shoreline [2]. Seawater desalination by MSF process generally requires a large seawater inlet flow resulting in an increase in salinity of the discharge flow known as brine. Various chemicals are added to the feed water to control formation of mineral scale and biological growth that would otherwise interfere with the processes [3]. These chemicals or their reaction products are in-turn discharged with the reject brine. Cooling water used in the steam turbine generators is also discharged to the sea with higher temperature than the ambient temperature of the surface seawater. The potential negative impacts associated with desalination plant operation have gained an

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international attention [4]. The introduction of concentrated brine waste effluent has been historically considered a major environmental concern with desalination plants particularly on marine ecosystem [5-8]. The discharged brine is characterized by increased salinity and elevated temperature. It additionally contains substantial amounts of chemical pollutants, such as chlorine (which is used for biofouling control in the plants), antiscalants (which are used for scale inhibition) and heavy metals (which are present due to corrosion). Desalination impacts on marine environment vary widely and are typically based on the specifics of each site. The degree of the impacts in a large part depends on overall plant design and operation, methods used for effluent disposal and specific physical and biological conditions near the plant. This aim of this work is to study the physical and chemical impacts caused by the effluent discharge from Az-Zour desalination plant in Kuwait on the local marine environment.

2. Desalination in Kuwait

In Kuwait, six coastal sites were developed to produce distilled water and electrical energy as shown in Fig. 1. Total current installed nominal capacity amounts to 2.81 million m^3/d [2]. The MEW (Ministry of Energy & Water) operates the MSF distillation plants at high temperature, mainly during high demand season (summer), whereas, operation at normal temperature is adopted during the rest of the year. Details of the installed capacity of the existing distillation plants in Kuwait are listed in Table 1.

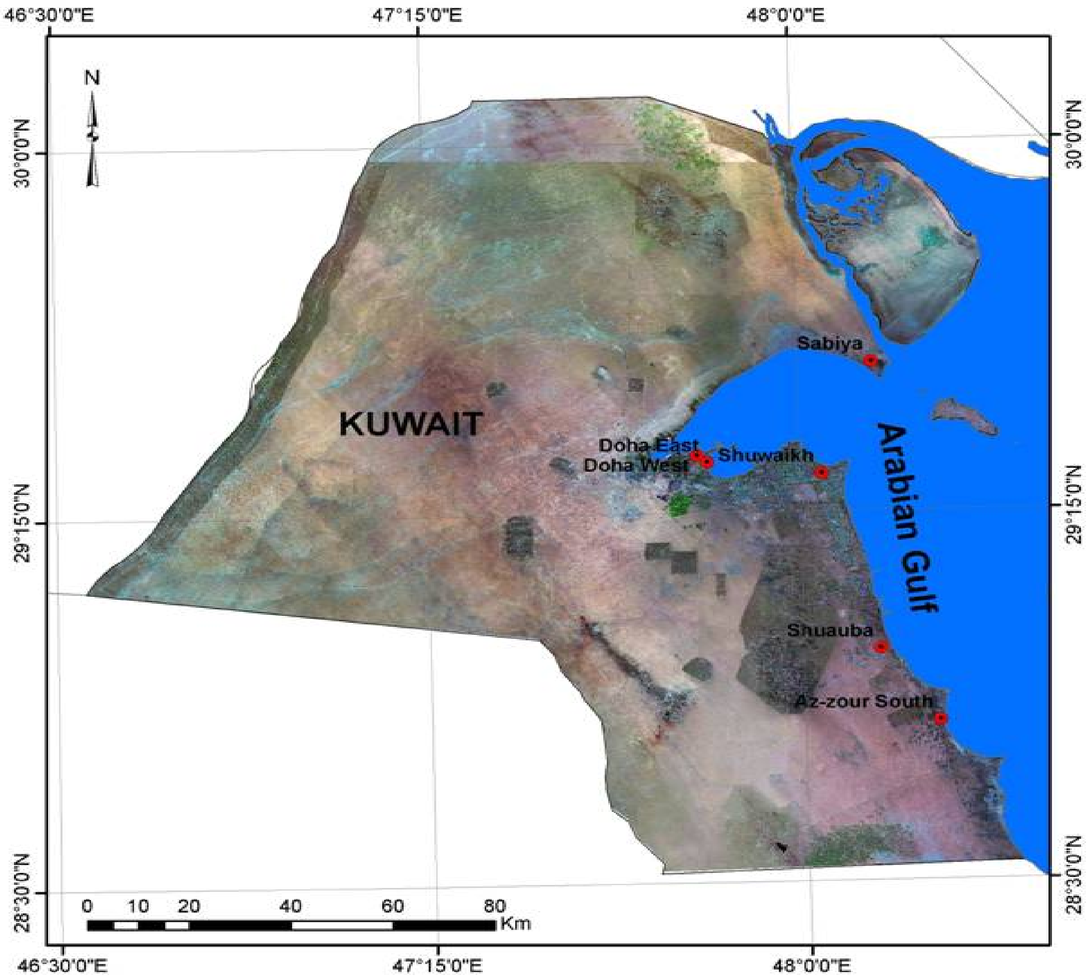

Fig. 1 Desalination and power plants in Kuwait.

Table 1 Installed capacity of the distillation plants in Kuwait.

Plant	Total capacity (million m^3/d)
Shuwaikh	0.221
Shuaiba	0.161
Doha East	0.189
Doha West	0.500
Az-Zour South	0.649
Sabiya	0.448
Total	2.81

3. Marine Environment Concerns

The Arabian Gulf represents an extreme case as to the undesirable environmental effects associated with brine disposal in comparison to other seas. This is because of the huge amount of desalination activities located relatively within close distance along the western seashores of the Gulf, which are considered the biggest of their kind in the world, and due to the distinctive characteristics of the Gulf itself in terms of the restrictions to the natural seawater circulation and evaporation rates. Hence, examining the case of its Arabian Gulf is useful in magnifying the impact of desalination on the marine environment, and hence, drawing a conservative conclusion on the extent of the undesirable effects. The natural circulation exchanges water between the Arabian Gulf and the Gulf of Oman via the Strait of Hormuz. The circulation in and out of the Strait of Hormuz is believed to be very limited with a residence time estimated to be in the range of 2 to 5 years [9, 10]. The evaporation is very high for most of the year, estimated at a rate between 140 and 500 cm/year [11]. Evaporation from the surface of the Gulf seawater exceeds the total river runoff and rainfalls by approximately a factor of 10 [12]. All these factors together contribute to making the salinity higher in comparison to other open seas. Salinity of the Gulf seawater varies seasonally, on the average, from 38,000 to 45,000 mg/L. In general, the salinity is higher during summer and fall, as compared to winter and spring seasons. Temperature of the Gulf seawater ranges from 12 to 35 ^{o}C in the winter and summer, respectively, with an average of 23.1 ^{o}C [13]. Thermal desalination plants discharge the concentrate usually with a temperature of 5 to 10 °C above ambient seawater temperature [5]. However, several authors investigated the effect of hot brine and they found that a small temperature elevation was noticed when discharging effluent at a temperature of 10-15 °C above ambient seawater temperature [14].

4. Material and Methods

4.1 Study Area and Sampling Locations

A total area of about 2 km at the vicinity of the marine area of Az-Zour desalination and power plant was assessed as shown in Fig. 2. Transects were established perpendicular to the coast and extend 2 km north and south or east and west from the outfall channel, taking into consideration the local condition and the technical specification of the intake and outfall channel. About 15 to 20 sampling points from 3 to 5 transects were selected, and sampling stations at successive increasing intervals from the outfall point were identified by GPS (Global Positioning System). Two water depths including surface and bottom were included in the assessment at these sites when feasible.

4.2 Sampling Procedure

Two sampling programs were carried out in the study. The first field sampling program was carried out between 6 and 28 August 2007. This program represented the summer season. The second sampling was carried out between 18 February and 25 March 2008 and represented the spring season. The sampling programs were hampered by the prevailing weather conditions, and thus, were done when conditions allowed. The surveyed stations with their GPS locations and water depth are shown and given in Table 2 and Fig. 3. Sampling was conducted according to the ROPME (Regional Organization for the Protection of Marine Environment) Manual [15]. In addition, water samples were also collected from more than one position within the plant. The sampling positions included the

Fig. 2 Az-Zour desalination plant and outfall structure.

Table 2 Location and water depth of sampling stations at the study area of Az-Zour desalination plant.

Station code	Distance (m)** /Transict	GPS Coordinate North East		Water depth (m)*
Zr 1	100 E	28.69843	48.37995	1.7
Zr 2	300 SE	28.69688	48.38183	5.2
Zr 3	100 S	28.69774	48.37962	2.5
Zr 4	100 N	28.69981	48.38006	4.8
Zr 7	300 NE	28.7	48.38006	5.4
Zr 8	500 SSE	28.69366	48.38226	4.6
Zr 9	500 ESE	28.69398	48.38793	5.5
Zr 10	800 NE	28.70015	48.3866	5.4
Zr 11	500 NE	28.70155	48.38408	5.3
Zr 12	1000 ESE	28.69398	48.38793	5.8
Zr 13	1000 E	28.6979	48.3899	6.1
Zr 14	1000 SE	28.691	48.3878	5.6
Zr 15	1000 NE	28.70298	48.38868	8.9
Zr 16	2000 SE	28.6892	48.39591	5.0
Zr 17	2000 E	28.6971	48.39883	6.6
Zr 18	2000 SSE	28.68405	48.39	4.0
Zr 19	2000 ESE	28.69037	48.39693	6.7
Zr 20	600 N	28.70376	48.38723	3.3
Zr 21-Control	2000 NE	28.70758	48.39723	7.0

* Depth as measured at the time of sampling.

** Distance and direction from the outfall point; N (North); NE (Northeast); E (East); S (South); SE (Southeast); SSE (South-southeast); ESE (East-southeast).

brine effluents discharged from the desalination units them self (i.e. reject brine in the syphon shaft), the effluent discharged from the power plant only (cooling water discharge) and effluent discharge at the outfall point of the plants (i.e., the mixing zone of the effluent from the distillation and power units together).

4.3 Analytical Measurements

All samples were analyzed to measure the physico-chemical characteristics of water including water temperature, salinity, pH, Dissolved Oxygen (DO) and conductivity at each sampling station and selected depth. The laboratory chemical analyses of collected samples included measurement of both inorganic and organic parameters. The work of all chemical analysis to determine the elements chemical readings was made according to the standard methods [16].

4.4 Numerical Modeling Assessment

The RMA-10 hydrodynamic model was used in this study to investigate the plume dispersion and simulate different scenarios of plume impacts. RMA (Resource Modeling Associates) developed the model, which is capable of modeling tidal fluctuation, current, temperature, salinity and conservative material. The model is based on the finite element technique and has the advantage of using a non-structured grid for the domain network.

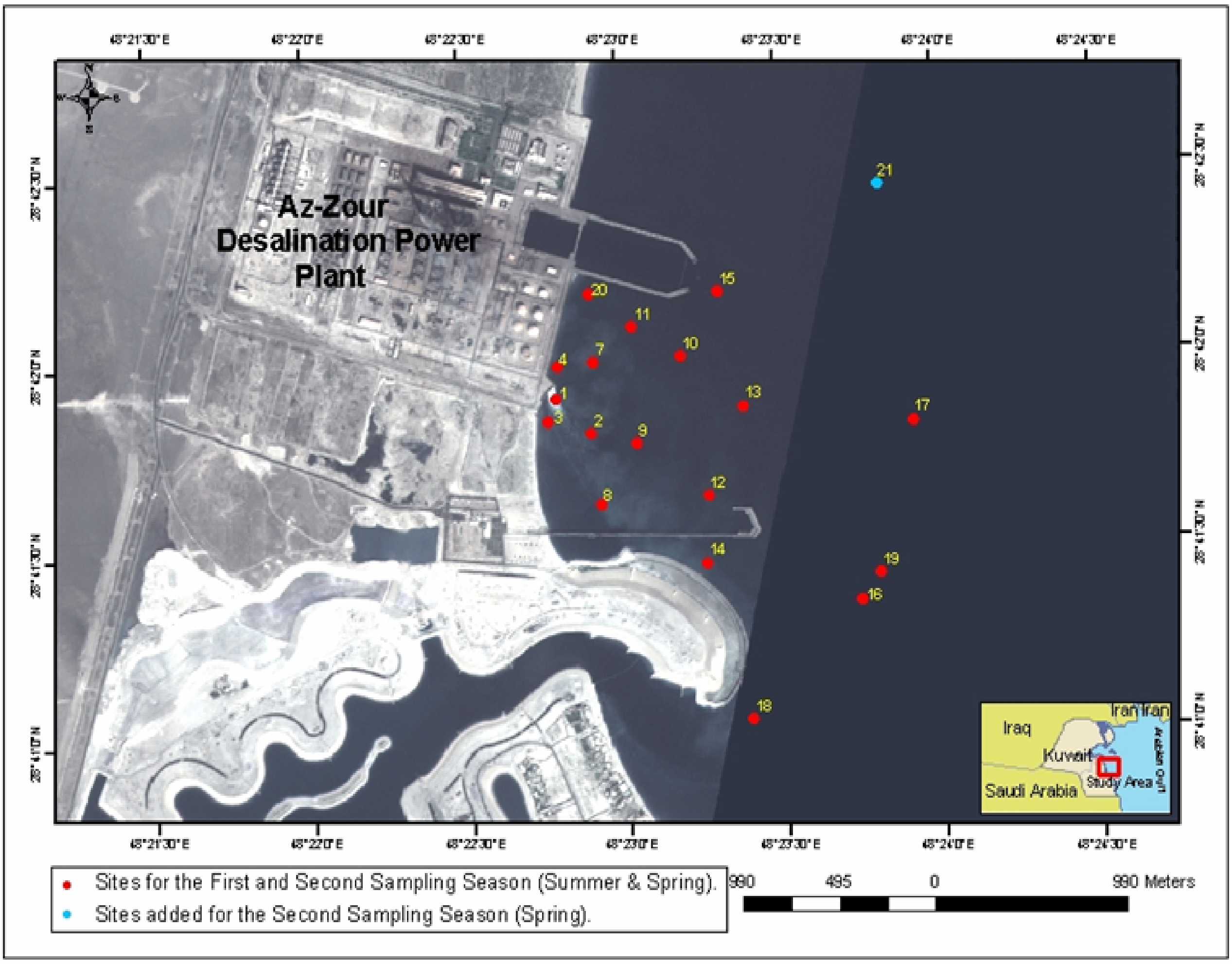

Fig. 3 The sampling stations at the study area of Az-Zour desalination plant.

5. Results and Discussion

5.1 Impact of Temperature Rise

Water quality measurement at the vicinity of Az-Zour plant was carried out twice in two seasons; summer season in August 2007 and in spring in March 2008. In summer, water temperature was found to range between 33 °C (at Zr 19 located 2,000 m ESE direction from the outlet), and 37.55 °C (at Zr 3 located at the discharge point at 100 m south) in the surface water layer. In the bottom water, the temperature ranged between a minimum of 33 °C (at Zr 19 located 2,000 m ESE and Zr 20 located 200 m north the outlet), and 38.7 °C at station Zr 7 (300 m NE of the outlet) with an average of 35.01 ± 0.38 °C, for both surface and bottom water temperature (Table 3). In general, temperatures distribution showed a decreasing trend from the outfall discharge point toward offshore. On the average, 2 to 3 °C difference in temperature was noted between stations close to the discharge point, and those further away (> 1.5 km) (Fig. 4). Spatial distribution of temperature in the surface layer and the same in the bottom water layer during this season are shown in Figs. 4 and 5.

During spring, the temperature in the surface water layer ranged between a minimum of 16.25 °C at station Zr 19 (2,000 m southeast direction from the outfall) and a maximum of 24 °C at station Zr 14 (located about 1,000 m southeast the outlet along the directions of the discharge) (Table 3). The plume results in an increase of 6 °C above ambient water temperature during this time of the year. Stratification within the water column was generally stubble. However, differences in water temperature attributed to stratification were demonstrated at stations Zr 1, Zr 8, Zr 15 and Zr 20 where surface temperature was more than temperature of bottom water layers by 2.85, 2.69, 1.1 and 1.83 °C, respectively (Table 3 and Fig. 5). The increase signified in surface temperature at Zr 15 and Zr 20 is of particular importance as these stations located at the area of the plant water intake, and thus may be contributing to increase in water temperature at the plant intake. This increase, unlike in summer season where the ambient temperature is already high, is an advantage in the winter for the desalination process. In contrast, stations Zr 8, Zr 9 and Zr 14 exhibited higher temperatures at the bottom water layers compared to the surface temperature (+1.6, +4.49 and +2 °C, respectively) at the vicinity of Zr desalination plant (Figs. 4 and 5). Thermal increase ranged between 4 and 6 °C. These temperatures are low when compared to Kuwait guidelines for industrial wastewater discharge to the sea. According to these guidelines, the maximum allowable limit for discharge of industrial wastewater to the sea is ≤ 10 °C, calculated as the difference between the temperature of discharged water and that of the intake [17].

Table 3 Water quality measured at the vicinity of Az-Zour desalination plant.

Station code	Level	Conductivity (EC) (ms/m)		DO (mg/L)		pH		Water temp. (°C)		Salinity (ppt)	
		Summer	Spring	Summer	Spring	Summer	Spring	Summer	Spring	Summer	Spring
Zr-1	Top.	63.74	-	-	6.65	7.68	7.93	37.41	23.1	42.56	40.02
	Bott.	-	-	-	6.97	-	7.91	-	20.25	-	39.76
Zr-2	Top.	61.63	-	-	6.57	8.88	7.94	35.27	21.57	41.06	39.2
	Bott.	64.4	-	-	6.83	8.87	7.94	35.32	21.43	43.15	39.65
Zr3	Top.	65.14	-	-	6.7	8.63	7.93	37.55	22.73	43.66	40.56
	Bott.	-	-	-	6.75	-	7.92	-	22.5	-	37.56
Zr4	Top.	63.98	-	-	6.61	8.65	7.92	34.1	21.53	42.91	39.51
	Bott.	65.3	-	-	6.66	8.88	7.93	37.38	21.03	43.75	39.1
Zr-7	Top.	63.54	-	-	6.57	8.88	7.93	33.74	21.02	42.59	40.67
	Bott.	63.55	-	-	6.69	8.87	7.91	38.72	20.22	42.59	38.6
Zr-8	Top.	65.3	-	-	7.14	8.88	7.92	37.38	21.84	43.75	38.18
	Bott.	65.27	-	-	6.89	8.85	7.92	37.38	22.18	43.74	39.54
Zr-9	Top.	63.37	-	-	7.24	8.86	7.91	33.76	19.49	42.48	38.46
	Bott.	63.88	-	-	7.12	8.86	7.92	34.18	24.3	42.88	35.2
Zr-10	Top.	64.22	-	-	7.19	8.85	7.91	35.16	19.81	43.14	40.39
	Bott.	63.39	-	-	7.24	8.84	7.91	34.6	19.49	42.83	38.46
Zr-11	Top.	64.44	-	-	7.33	8.85	7.93	35.56	19.59	43.18	41.77
	Bott.	63.59	-	-	7.19	8.81	7.91	34.76	19.53	42.6	40.71
Zr-12	Top.	63.36	-	-	7.41	8.86	7.37	33.83	17.71	42.45	40.69
	Bott.	63.72	-	-	7.33	8.85	7.9	34.06	18.52	42.72	40
Zr-13	Top.	64.43	-	-	7.46	8.85	7.83	35.72	16.83	43.17	40.73
	Bott.	63.85	-	-	7.15	8.84	7.86	34.53	17.21	42.81	39.42
Zr-14	Top.	63.99	-	-	7.08	8.86	6.98	34.52	24	42.9	42.09
	Bott.	63.99	-	-	7.06	8.86	7.93	34.52	260	42.9	40.65
Zr-15	Top.	35.32	-	-	7.4	8.86	7.85	34.98	16.96	42.9	39.89
	Bott.	63.6	-	-	7.55	8.84	7.84	34.22	15.86	42.6	38.69
Zr-16	Top.	77.91	-	-	7.39	8.65	7.81	35.91	18.2	43.24	40.54
	Bott.	76.55	-	-	7.54	8.81	7.8	34.6	18.5	43.43	39.49

Table 3 to be continued

Zr-17	Top.	72.66	-	-	7.55	8.8	7.86	33.33	16.92	41.96	40.66
	Midd.	72.61	-	-		8.78	-	33.29	-	40.95	-
	Bott.	72.61	-	-	7.28	8.72	7.84	33.28	16.68	41.97	39.3
Zr-18	Top.	77.4	-	-	6.93	8.66	7.88	35.4	17.19	43.28	41.36
	Bott.	76.5	-	-	7.07	8.77	9.08	34.8	18.39	43.23	40.01
Zr-19	Top.	71.98	-	-	7.35	8.76	7.85	33	16.25	41.78	40.09
	Midd.	-	-	-	-	-	-	-	-	-	-
	Bott.	72.05	-	-	7.04	8.62	7.85	33.01	16.5	41.82	39.14
Zr-20	Top.	64.38	-	-	7.1	8.36	7.93	35.03	21.56	43.18	40.56
	Bott.	63.59	-	-	6.99	8.81	7.89	34.76	19.73	42.6	39.00
Zr-21 control	Top.	-	-	-	7.24	-	7.88	-	20.06	-	40.17
	Bott.	-	-	-		-	7.84	-	18.8	-	38.51
Max.	Top.	77.91	-	4.97	7.55	8.88	7.94	37.55	24	43.75	42.09
	Midd.	72.61	-	2.28		8.78	-	33.29	-	40.95	-
	Bott.	76.55	-	4.50	7.55	8.88	9.08	38.72	26	43.75	40.71
Min.	Top.	35.32	-	1.28	6.57	7.68	6.98	33.00	16.25	41.06	38.18
	Midd.	72.61	-	2.28		8.78	-	33.29	-	40.95	-
	Bott.	63.39	-	2.15	6.66	8.62	7.80	33.01	15.86	41.82	12.07
STDEV	Top.	8.85	-	0.85	0.33	0.29	0.24	1.37	2.40	0.67	0.98
	Bott.	4.82	-	0.51	0.26	0.07	0.28	1.53	2.64	0.53	6.32
Average	Top.	64.82	-	2.85	7.1	8.71	7.82	35.09	19.81	42.79	40.29
	Bott.	66.620	-	2.79	7.08	8.82	7.95	35.01	19.85	42.85	37.7

Top level is within 1 m from sea surface. Bottom level is within 1 m above seabed. Middle level is the middle depth.
Summer (August 2007); Spring (March 2008).

5.2 Impact of Salinity

Salinity impact at the marine area adjacent to the desalination plant occurs when brine containing higher content of salt and minerals above ambient level is discharged through the plant outlet. Changes to salinity can play a significant role in the growth and size of aquatic life and the marine species disturbance. Water salinity was measured at two water depths to assess salinity gradient with depth in relation to the plant discharge effluent. Salinity of water surface during summer ranged between a minimum of 41.06 ppt (at station Zr 2, 300 SE) and a maximum of 43.75 ppt (at station Zr 8, 500 SSE) with an average 42.79 ppt (Table 3). In the bottom water layer, concentration of salinity was from 41.82 ppt (Zr 19 2000 m ESE from outlet) to a maximum of 43.75 ppt (Zr 8, 500 m SSE) in the direction of the flow with an average 42.85 ppt. The distribution of water salinity in the surface and bottom layer was small (< 1 ppt, Fig. 6).

In Spring, surface water salinity ranged between a minimum of 38.18 ppt (Zr 8) and a maximum of 42.09 ppt (Zr 14, Table 3) with an average 40.29 ppt. Highest salinities were exhibited in stations between 500 and 1,000 m towards the northeast and southeast of the outfalls (Fig. 7). Impact close to the outlet was not found high (Fig. 7). At the bottom water layer, salinities ranged between a minimum of 35.20 ppt (Zr 7) and a maximum of 40.17 ppt (Zr 11, 500 m NE) with an average 39.18 ppt. Highest salinities at the bottom layer were exhibited closer to the outlet in the area less than 1,000 m, contrary to the surface water (Fig. 7). The difference of water salinity between the highest measurement recorded in summer and the highest recorded in spring in surface was 1.66 ppt, while the difference was 2.88 ppt in the bottom water layer (Table 3). Potential impact of the salinity at the vicinity of the studied area was found to range between 2-4 ppt above mean salinity of seawater in Kuwait in the two seasons. The impact can reach as

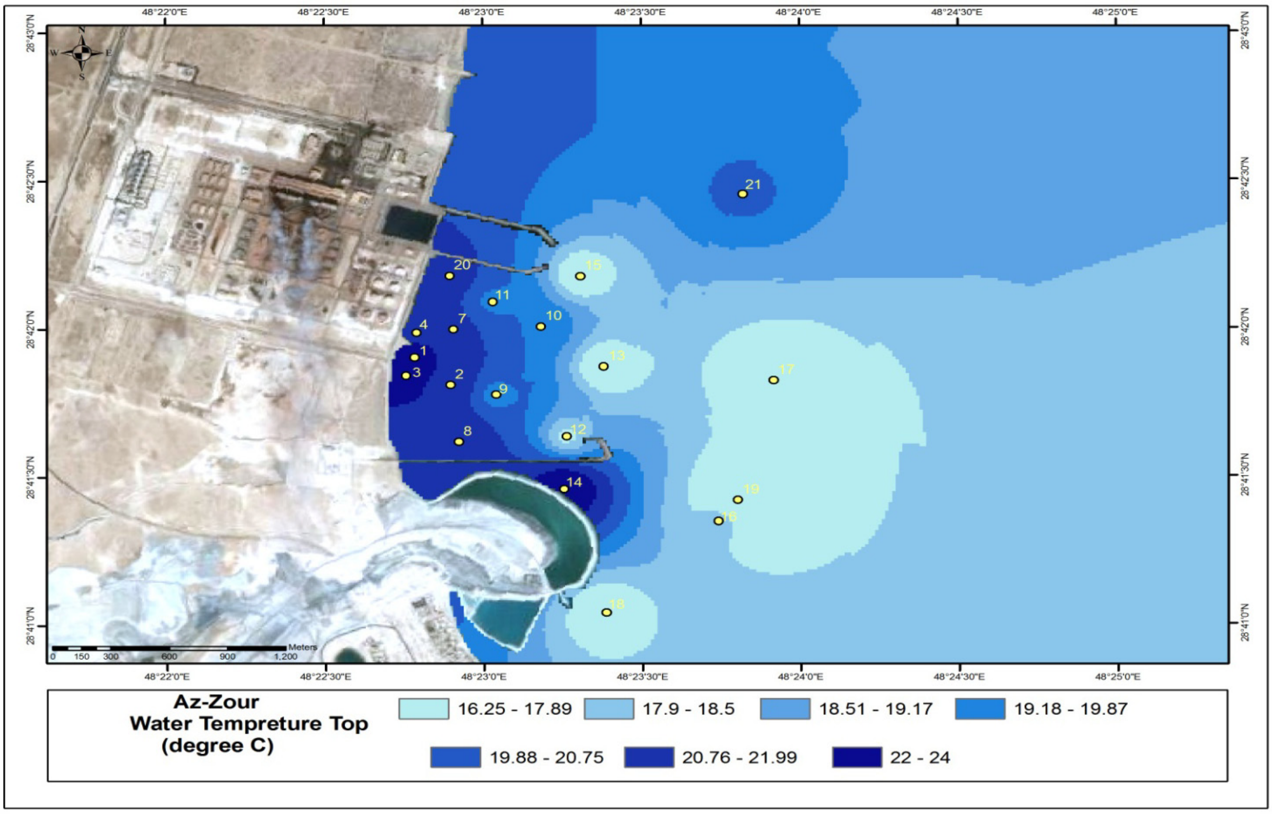

Fig. 4 Spatial distribution of surface water temperature at the vicinity of Az-Zour desalination plant during summer season.

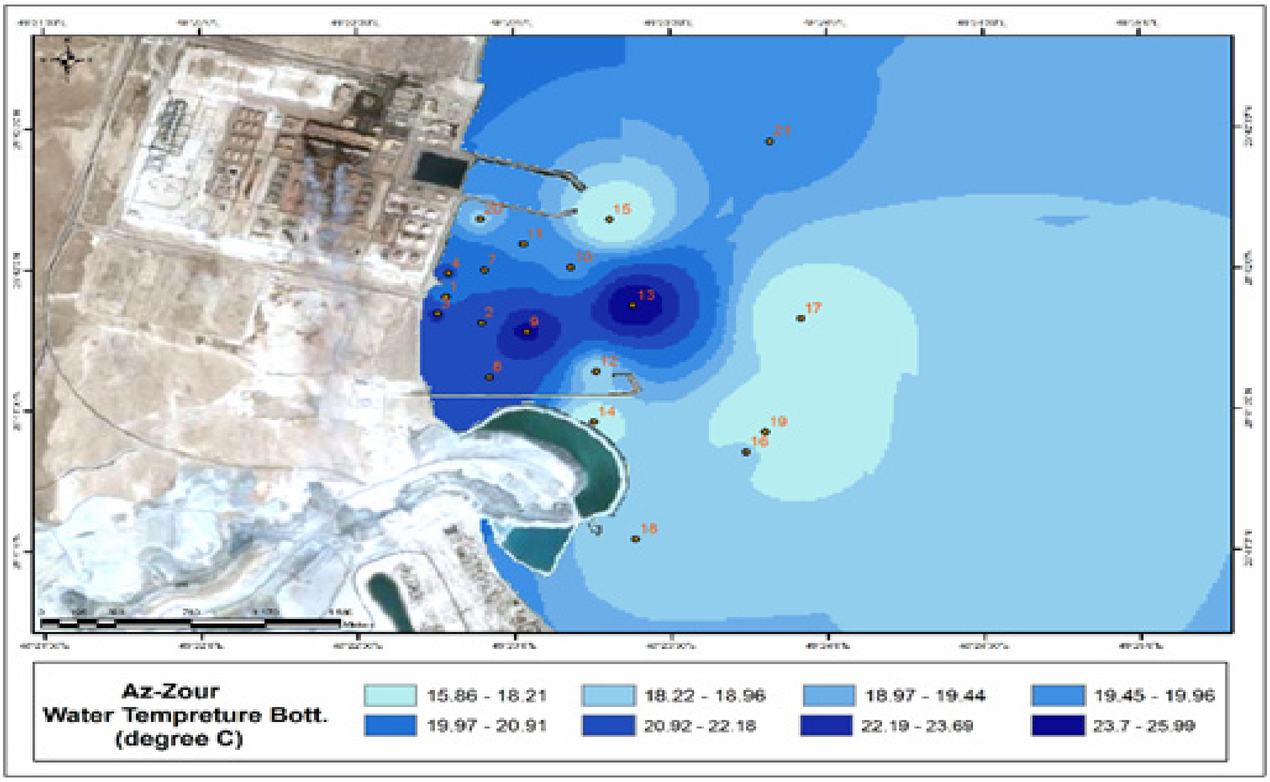

Fig. 5 Spatial distribution of bottom water temperature at the vicinity of Zr desalination plant during spring season.

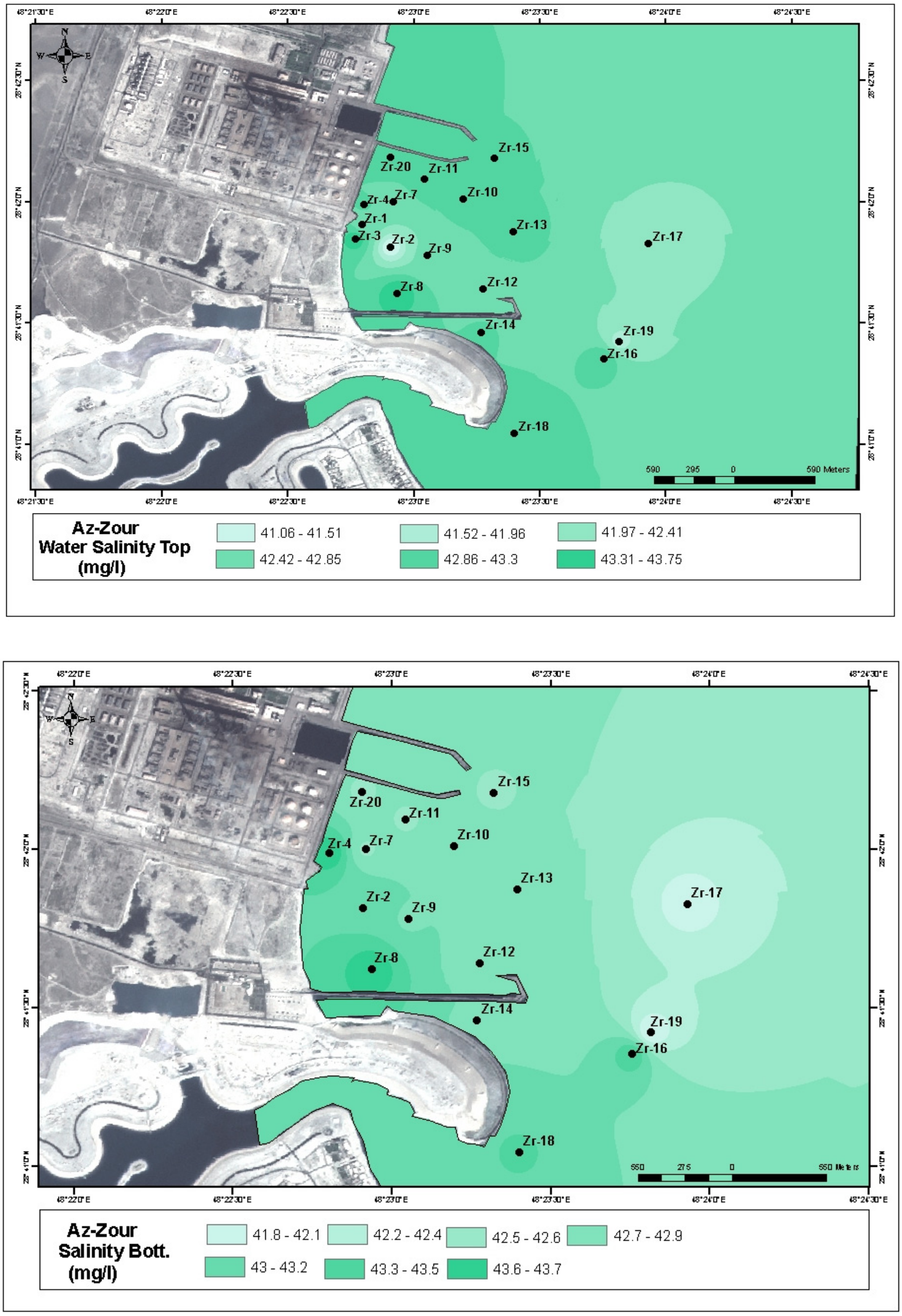

Fig. 6 Spatial distribution of salinity in surface and bottom water layers at the vicinity of Az-Zour desalination plant during summer season.

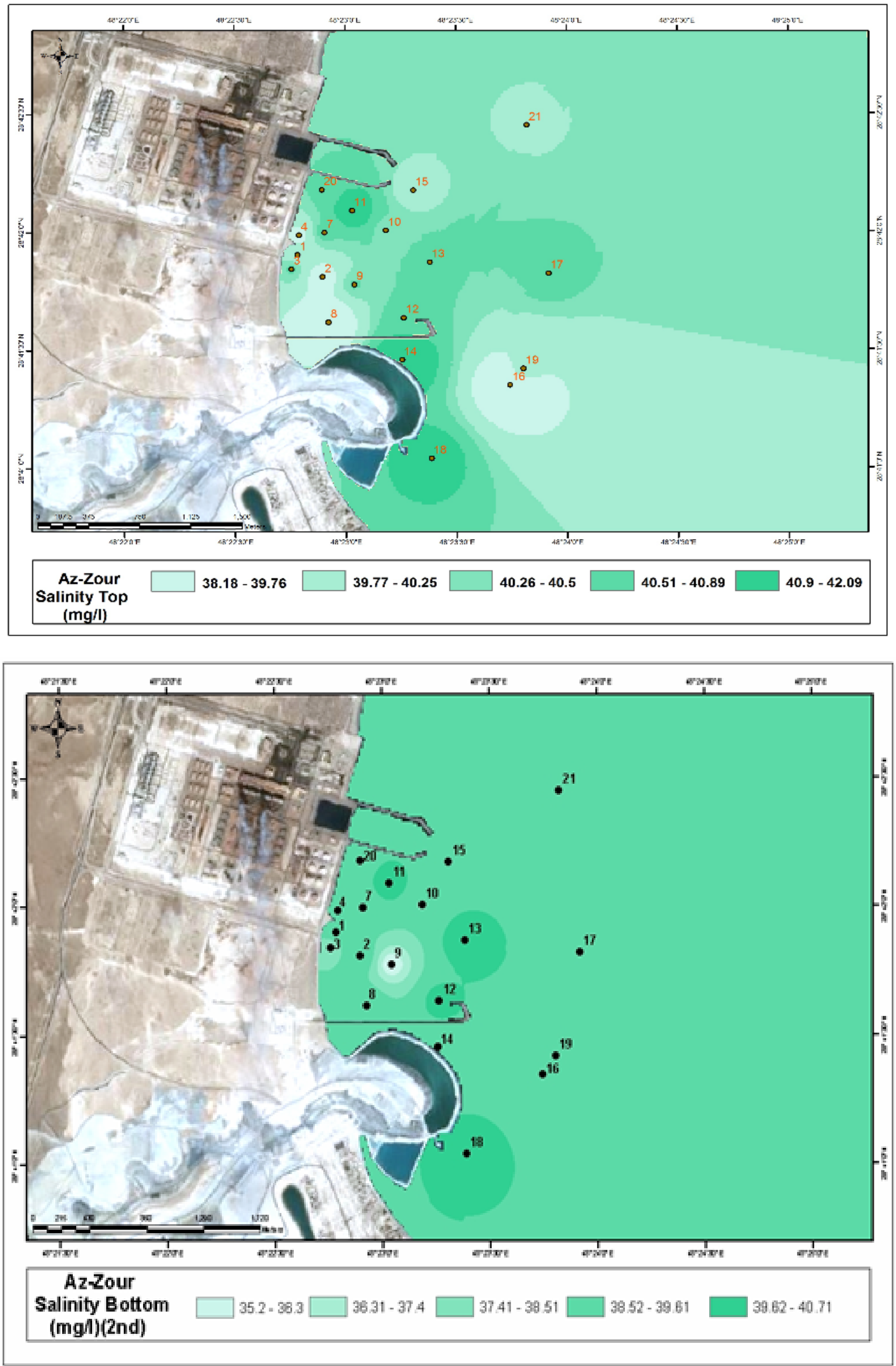

Fig. 7 Spatial distribution of salinity in surface and bottom water layers at the vicinity of Az-Zour desalination plant during spring season.

far as 1,000 m away from the plant outfall. The increase in salinity above mean value at the vicinity of the plant is higher than the limit of 33-42 ppt set by Kuwait Environmental Authority (EPA) for seawater quality [17].

5.3 Impact on DO

Increased temperature and salinity of the discharged effluent from desalination plant reduce the solubility of DO in seawater. Levels of DO may be reduced because of the physical deaeration and addition of oxygen scavenger such as sodium sulphite to inhibit corrosion inside the plants. Table 3 shows the concentrations of DO at the vicinity measured in spring at the two water depths; surface and bottom (no measurements could be made during summer due to instrument failure during fieldwork). In spring, surface DO levels were higher and ranged between a minimum of 6.57 mg/L (Zr 2, 300 m southeast the outfall) and a maximum of 7.55 mg/L recorded at station Zr 17 (2,000 m east the outfall). EPA monitoring data for DO Az-Zour was 8.8 mg/L in March 2008 [18]. In the bottom water, DO was found to range between 6.66 mg/L (Zr 4, 100 m north the outfall) and 7.55 mg/L at station Zr 17 (2,000 m east the outfall), where in many stations, DO in bottom station was slightly higher than surface water. Normally under stratified conditions, the DO concentration is lower in the bottom layer than in the surface layer, as oxygen is consumed by decaying organic matter. Near the outfall, DO concentration is lower in the surface layer than in the bottom layer. Hence, it is thought that this is a direct result of the outfall. As the outfall plume is slightly buoyant (the density is lower than the receiving seawater), it tends to rise to the surface layer. As the outfall plume has a lower DO concentration, the surface layer shows a lower DO concentration than the bottom layer.

Kuwait has set a minimum standard of 4 mg/L or 90% saturation whichever is higher for marine water quality [17]. The above-mentioned results at the vicinity Az-Zour plant showed that DO levels were above this limit.

5.4 Impact on pH Levels

At the vicinity of the desalination plant, measurements recorded for pH, expect for station Zr 1 (at the discharge outlet), were all above 8 (ranging from 8.36 to 8.88). Surface water pH levels were similar to the levels in bottom water layer (see Table 3). In spring, pH levels were higher than in summer and were generally about 8 in most of the stations except at station Zr 14 and Zr 12 where it was found to be slightly lower (7 and 7.4). When compared to surface levels, pH readings in bottom water showed no significant difference (Table 3) and generally within Kuwait-EPA limits and therefore no significant impact of pH was observed [17].

6. Conclusions

Measurement of temperature at the marine vicinity of the investigated Az-Zour desalination plant showed an increase between 4 and 6 °C above ambient temperature in which the seasonality conditions were taken into account. In general, temperature showed a decreasing trend from the outfall discharge point toward offshore. On the average, 2 to 3 °C difference in temperature was noted between stations close to the discharge point, and those further away (> 1.5 km). The hydrodynamic model employed in this study gave a prediction of temperature dispersion near Az-Zour marine areas. It showed that the thermal plume rans parallel to the shoreline. The area influenced by the outfall can reach to about 40 km^2. Potential impact of salinity at the vicinity of the Az-Zour plant was found to range between 2-4 ppt above mean salinity of seawater in Kuwait in the two seasons. The impact can reach as far as 1,000 m away from the plant outfall. The increase in salinity above mean value at the vicinity of the investigated plants is higher than the limit of 33-42 ppt dictated by Kuwait EPA regulations for seawater quality.

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Study on Using Biological Sludge from Vinh Loc Industrial Park to Produce Composting Product

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Abstract: In order to examine the optimal design and operating parameters in composting of waste activated sludge, a series of experiments were conducted to discuss the optimal operating parameters for aerobic composting of waste activated sludge obtained from Vinh Loc Industrial Park that is located in Ho Chi Minh City. The study was done by optimizing the ratios of sludge/inactive fillers and sludge/microbial products to improve the composting efficiency. After 50 days of composting, the composts of all experiment batches met the microorganism-organic fertilizer standards of 10 TCN 526:2002. The study indicated that the highest efficiency decomposition was obtained at the ratio of a sludge/inactive fillers of 1/0.1 and sludge/microbial products of 1/0.05: TOC (Total Organic Carbon) reduced by 20.2%, loss of Nitrogen was trivial (0.53%), the highest temperature reached at 55.5 ^{o}C and lasting for 5 days which ensures elimination of pathogens. However, the addition of nitrogen compounds during the composting is necessary to ensure the compost product can meet the nitrogen standard of microorganism-organic fertilizer.

Key words: Biological sludge, microorganism-organic fertilizer, aerobic composting, reuse of sludge, inactive fillers.

1. Introduction

Sewage sludge, a product of wastewater treatment, is rich in nutrients and trace elements and could be re-used in agriculture as fertilizer and soil conditioner. High odour emission, high levels of heavy metals and toxic organic compounds, and the presence of potentially pathogenic microorganisms, demand pretreatment of sewage sludge before application in agriculture.

Composting is a successful strategy for the sustainable recycling of organic wastes. Since composting is an inexpensive, simple and environmentally sound process for waste disposal, the composting of thickened and dewatered undigested primary and secondary sludge has been widely applied [1]. Composting improves the handling characteristics of organic residue by reducing its volume and weight. Therefore, received increasing amounts of interest and have been developed for treatment of waste activated sludge [2]. Aerobic composting, which is the decomposition of manure or other organic materials in the presence of oxygen, is one of the waste activated sludge treatment processes. In the aerobic composting process, the decomposition of organic materials is promoted by adequate aeration. However, excessive aeration causes a change to the worse in composting because the temperature of the reactor and moisture content of the material decrease [3]. It is important, therefore, that the amount of aeration is managed at the appropriate level to conduct composting efficiently.

Waste activated sludge, in general, has a higher moisture content than is desired, a substance with a lower moisture content has to be added. Materials utilized for this purpose are called organic amendments or bulking agents [4]. The dewatered sludge might lack sufficient porosity for adequate aeration. Bulking agents are needed to provide structural support when the composting materials are too wet to maintain air spaces within the composting pile, and to reduce moisture content. In addition, these

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materials may be used to balance the C/N ratio, increase its porosity and prevent excessive compaction of the composting materials.

The objectives of the present work are to examine the optimal ratio of waste activated sludge/inactive fillers and waste activated sludge/microorganism for composting under aerobic conditions. The most important physico-chemical parameters such as temperature, pH, TOC, total N and C/N ratio were monitored.

2. Materials and Methods

2.1 Preparation of Composting Mass

Waste activated sludge obtained from Vinh Loc Industrial Park located in Ho Chi Minh City, Vietnam, was dewatered to a water content of approximately 60-70%. Fifty kg of dewatered sludge were prepared and composted in a batch composting system. The sludge was then minced and mixed with inactive filler as the bulking agent. The inactive filler was obtained from rubber production factory after grounding to a particle size of 1-2 cm. Microbe-Lift IND was a microbial liquid culture that is 5 to 10 times more potent than conventional microorganism produced by Ecological Laboratories, the United States. It can break down fecal compounds, converting the nutrients in these compounds into more readily available formulations, accelerating the biological oxidation of organic compounds, substances slow organic decomposition [5].

2.2 Composting Experiments

The composting experiments were conducted in iron sheets of 1 m × 0.5 m. The reactor was equipped with eight perforated plastic pipes supplying air to the compost pile. A fine screen mesh was installed above the reactor bottom to segregate the compost pile from the aeration pipe. The composting material was manually turned once a day to ensure a homogeneous air distribution. Temperature was monitored before and after turning. Samples were withdrawn to measure moisture content, pH, total N, TOC at 1, 10, 20, 30, 45, 50 days of testing. At the end of study, samples were analyzed pH, TOC, total N, moisture content, TS, VS, K_2O, P_2O_5 and heavy metals.

The series of composting experiments were designed at different conditions: 6 aerobic composting batches with ratios of sludge and inert fillers 1:0, 1:0.3, 1:0.35, 1:0.4, 1:0.45, 1:0.5; 6 aerobic composting batches supplemented with microbiological preparations as ratios 1:0, 1:0.02, 1:0.05, 1:0.08 and 1:0.1.

2.3 Analytical Methods

Total solid and volatile solid were determined by US EPA Method 1684. TOC, Total N, P_2O_5, K_2O were analyzed by TCVN 8941:2011, TCVN 6498:1999, TCVN 5256:2009, TCVN 8560:2010, respectively. Heavy metals were determined by AAS (Atomic Absorption Spectrophotometer) according to US EPA Method 3051A and SMEWW 3125B:2012 [6].

3. Results and Discussion

3.1 Temperature

Fig. 1 shows the temperature variations, a function of time.

Temperature variations of all batches were similar following “fast-declining-stable”. The early stage of the test increased slowly due to microbial adaptation, then temperature increased rapidly after 7 days and reached 53.5 ^oC after 15 days in MH2, higher than 9.5 ^oC compared with the highest temperature in the control batch. Temperature of this study was less than some previous studies such as composting from the pig manure (55 ^oC) [7], from the olive mill waste (62.3 ^oC) [8]. The high temperatures of the batches were maintained for 3-5 days and reached the optimum temperatures for composting (40-60 ^oC). The temperatures of sludge and inactive filler mixture were similar, and the highest value was achived after 23 days, it was slower than the compost with microbial incubation.

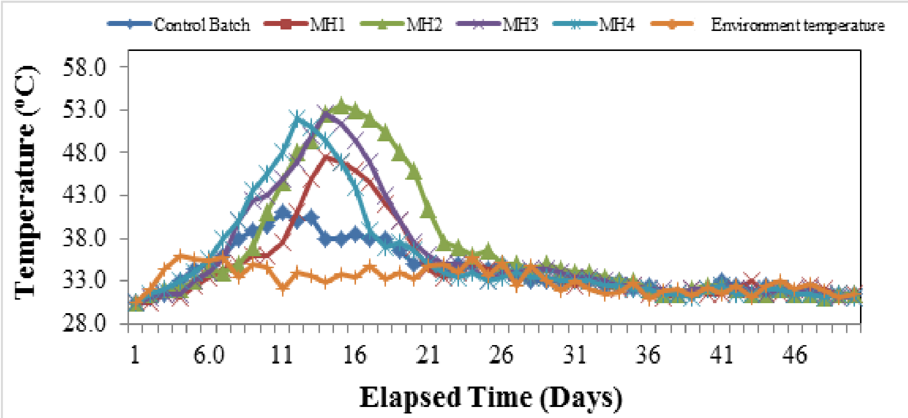

Fig. 1 Variation of temperature through time.

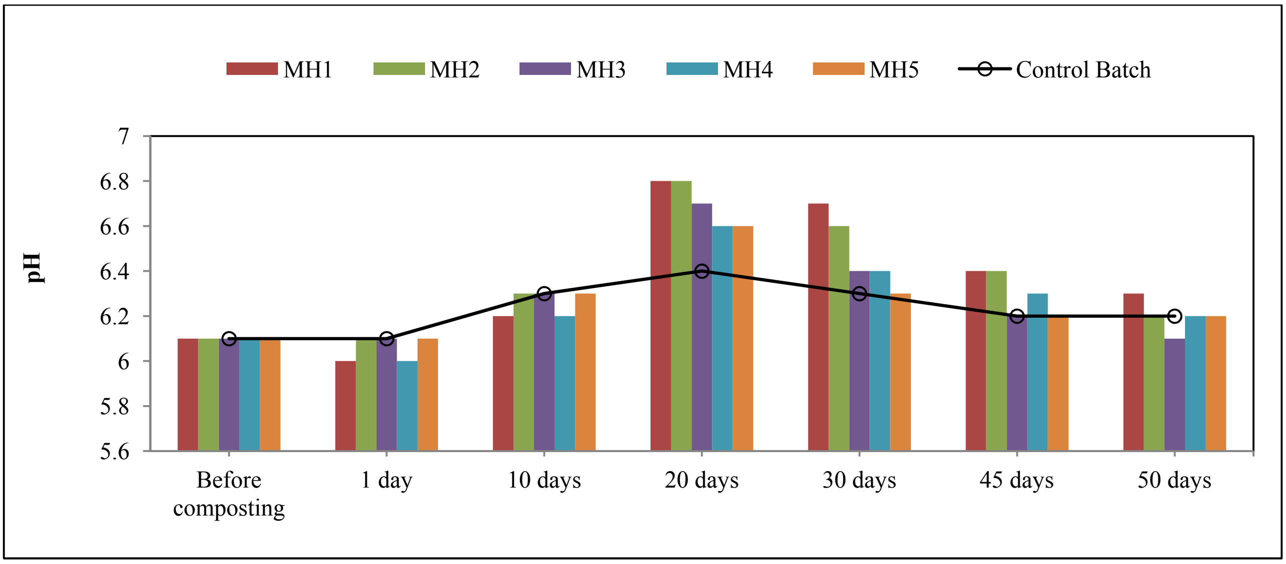

Fig. 2 Variation of pH through time.

3.2 pH

The pH variations were shown in Fig. 2.

The pH of early stage were reduced by bacterial adaptation. Bacterias consumed the substrate and organic compounds for growth, released organic acids at the same time, the accumulation of these acids led to decrease of the pH. Then, the pH increased rapidly from day 2 to day 20 of the test. It indecated that decomposition of organic acids by microorganisms has occurred in each batch, pH values gradually stabilized at the end of study. The pH values of batches which supplemented the microorganism were from 6.0-6.7. The similar pH values were obtained in the batches mixed with inactive filler (6.0-6.8). It was in the optimum pH range for bacterial activities (5.5-8.5).

3.3 Moisture

The changes of moisture were shown in Fig. 3.

Moisture is one of the important factors for bacterial growth. During the test, the moisture tended to decrease significantly due to the evaporation of water from the bed. In the first 25-30 days, the moisture content of the compost was monitored regularly. In the case, the moisture was too low, the water would be replenished to maintain optimal humidity (50-60%). After 30 days of the test, the composting was gradually stabilized, stopping adding water so that the moisture contents of the composting

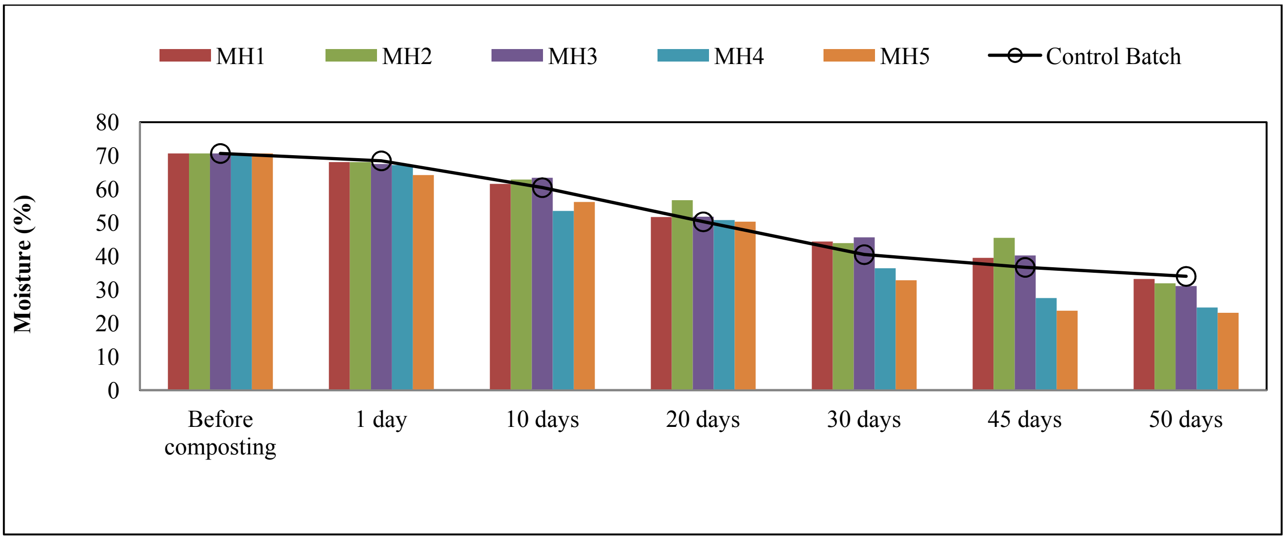

Fig. 3 Variation of moisture through time.

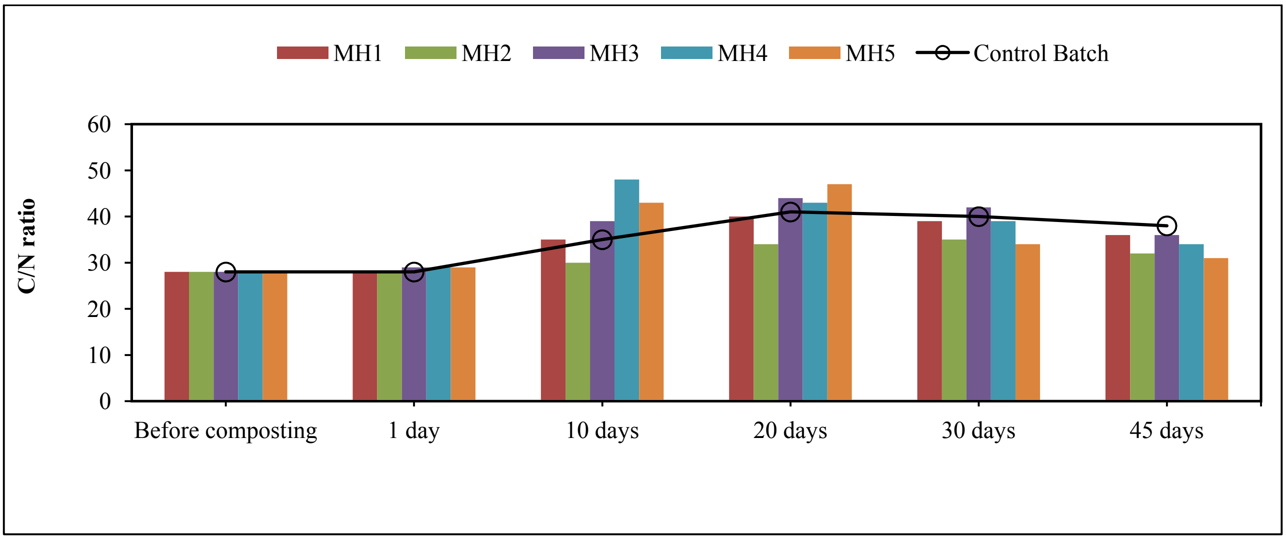

Fig. 4 Variation of C/N through time.

were maintained naturally. The moisture content of test was achieved 10TCN 526: 2002 (humidity < 35%). For the inert filler batches, the moisture content varied between 50.3-68.5% for the first 20 days and decreased gradually until the end of the test.

3.4 C/N Ratios

The changes of C/N of study were shown in Fig. 4.

The C/N ratio is an indicator of the decomposition of organic fertilizer. Fig. 4 showed that the C/N ratios of study were in the range of 21.3 to 28.4 and were within the optimum range for sludge decomposition. At the end of the experiment, the C/N ratio in the MH was less than the initial value (28.1), the C/N ratio of MH2 was the lowest with the value of 21.3. However, due to the low nitrogen content, the C/N ratio was still high. The results of this study were in a higher C/N ratio than that of Nguyen Van Phuoc, et al. [9]. The C/N ratios of batches mixed with inactive sludge were higher (32-37) than that of the microbial inoculation.

Results of study are presented in Table 1.

Table 1 shows that the quality of sludge after composting of all batches met the standard of organic compost except the low total nitrogen. Since the

Table 1 The analytical results of sludge after composting.

Parameters	Unit	Control batch	MH1	MH2	MH3	MH4	10TCN 526:2002
pH	-	6.2	6.1	6.1	6.2	6.1	6.0-8.0
Moisture	%	34.0	33.0	30.4	32.5	33.4	< 35
TS	%	65.6	68.9	68.6	67.8	67.7	-
VS	%	48.1	48.3	47.7	48.3	47.7	-
C/N	-	27.6	25.2	21.3	23.6	23.1	-
TOC	%	19.6	18.4	16.6	17.0	17.3	> 13
Total N	%	0.71	0.73	0.78	0.72	0.75	> 2.5
Total P	%	3.00	3.08	2.92	2.74	2.71	> 2.5
K_2O	%	1.49	1.50	1.50	1.52	1.51	> 1.5
E. coli	MPN/g	1.1×10^4	NA	NA	NA	NA	-
Salmonella	MPN/ 25 g	NA	NA	NA	NA	NA	0

*NA: Non- available.

temperature of the control batch was not high and the maximum temperature was maintained at a short time (40-41 °C for 3 days), after the end of the test, *E. coli* was still detectable in compost. However, after 50 days of study, the batches added microbial products were more stable, resulting in no presence of *E. coli* and *Salmonella* in compost product.

The results of the analysis indicated that the MH2 (sludge:microbial ratio of 1:0.05) had the highest efficiency of composting, all the parameters met the standard 10TCN 526: 2002.

The highest compost efficiency of batches mixed with inactive filler was obtained at MH1 (sludge/inactive filler ratio of 1:0.3). The TOC of it dropped from 36.8% to 17.3%, maximum temperature increased to 58.2 °C, and other parameters met standard organic fertilizer 10TCN 526: 2002 excluding total N content. Therefore, to improve the compost quality and meet the market demand, addition of nitrogen is necessary.

4. Conclusion

The biological sludge obtained from the Vinh Loc Industrial Park had potential as a raw material for producing compost. The sludge was mixed with inactive fillers, the nutritional parameters of mixture increased over time as the effective phosphorus content, potassium and some other criteria met fertilizer standard 10TCN 526: 2002 as TOC, moisture.

The results indicated that MH1 (the ratio of sludge/inactive filler of 1/0.3) had the highest composting efficiency with the highest reduction of total carbon content from 36.8% to 17.3%.

The optimum mixing ratio of sludge and microorganism was 1:0.05. Thus, the microbial composition had a positive effect on the composting, the quality of the compost was higher than that of the non-supplementary product, favorable environment for the composting, minimizing odor.

The result of this study indicated that this model can be applied in centralized wastewater treatment plants to address the emerging sludge problem. It is necessary to classify biological sludge and chemical sludge in order to have optimum treatment for each type of sludge, especially the reuse of sludge effectively.

Research on the effectiveness of composting product from bio-sludge applied to a number of vegetables, crops and ornamental plants need carried out for practical application.

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Socio-Cultural and Economic Role and Importance of Biodiversity and Forest in the Democratic Republic of Congo: Case of the Upper-Katanga Province

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Abstract: Biodiversity plays a fundamental role in the life of the Congolese population in general and in that of the population of Upper-Katanga province in particular. The current study deals with the socio-cultural and economic role and importance of biological diversity and forest in the life of the population of Upper-Katanga province. The utilized methodology was based on observation, field investigation and bibliographic research. Investigations were concerned more particularly with wood and animal species which are significantly utilized in the province. The results reflect the use of wood and animals which are part of the province biological diversity. They are compiled under two segments, namely the socio-cultural importance of biodiversity with some species forbidden to the queen, those that are utilized to split couples, to give strength to children, to provide the king with authority power, etc. The second segment deals with the results which emphasize the socio-economic importance of biodiversity concerned with hunting, fishing, cutting of some wood species for sale, building houses, cooking food, producing heat during cold weather, making furniture and other finished products, and for personal use.

Key words: Biodiversity, forest, socio-cultural and economic importance, Upper-Katanga province.

1. Introduction

Since the Neolithic period, men have been domesticating animals and plants to feed themselves better, to take care of their health, to get clothes and other animals for their strength, their milk, their meat, their leather... They benefit from living biodiversity in a wide range of activities and agricultural production under all the latitudes and on all the continents [1]. Biodiversity is constituted with the living organisms that surround us and to which we belong, it represents the living tissue of our planet. Its origin is very old because the first forms of life appeared on the Earth more than three billion and a half years ago. Since then, the living organisms have been changing to present the biodiversity we know today [2].

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Since a long time period, forest and wood represent important resources for the humanity. The forest plays a crucial role in the water cycle, the climate control and wood exploitation make multiple variations which represent a major challenge to the nation on ecological, economic and social plan [3]. Being the consumers who depend on wood energy, the poor people are generally the first ones who face the negative impacts which are heavy social charges, particularly the respiratory health problems. Despite those faced problems, the resident population of the Upper-Katanga province adjust themselves to the feeding, the culture and so on, an adaptation which makes them a real society. However, the Congolese biodiversity in general and that of the Upper-Katanga province in particular, is subject to threats by mining and forest exploitation, agriculture occupation of sites, wood cutting and carbonization, pirate fishing, military positions in the park, chasse poaching, commercial hunting, animal breeding, and human housing. There is housing destruction by itinerant agriculture on burnt down fields, hunting with bush fire, unsustainable forest exploitation inside and outside of protected areas, mining exploitation, group camping and armed gangs in protected areas. Besides, there is fauna destruction due to the destruction of habitats, to unrestrained killing of animals by unruly groups and armed gangs (Maï-Maï, FDLR, ADFNALU, LRA, SPLA), to chasse poaching with weapons for trophies and/or meat, to commercial hunting and to large scale hunting for subsistence [4].

In Central Africa, commercial hunting strongly contributes to supplying households with animal proteins in rural areas as well as in urban areas. It is accused to overexploit the fauna and to have a very negative impact on animal biodiversity and on forest regeneration, as well as creating important risks due to the development of emerging diseases [5]. On the other hand, biodiversity protection by the population of Upper-Katanga province is less striking/notable as the role or socio-cultural need of the population is absorbed by the economic one which leads to tree cutting, plant uprooting, hunting or to the extinction of certain animal species.

The objective of this paper is to identify and to define the role and the socio-cultural and economic importance of certain species of the biodiversity in the life of the population in Upper-Katanga province.

2. Methodology

The study was mainly carried out in the Upper-Katanga province located at 11°40′11″ South and 27°29′00″ East in the South-East of the Democratic Republic of Congo. After the administrative split of the former Katanga province into four new provinces (Lualaba, Tanganyika, Upper-Katanga, Upper-Lomami) in 2015, the Upper-Katanga became one of the current 26 provinces of the country. The province has an area of 132.425 square kilometers (km^2) and a population of 4,617,000 inhabitants [6]. It is limited at the North by the East of the Upper-Lomami province and the South of the Tanganyika province, at the East and the South by the Republic of Zambia and, at the Ouest, by the Lualaba province and the Upper-Lomami province. Lubumbashi is the capital city of the Upper-Katanga province. The province has six territories, notably Kambove, Kasenga, Kipushi, Mitwaba, Pweto and Sakania.

For data collection, authors resorted to methods such as observation, field investigation and bibliographical research.

The various products encountered at the four selling sites of Lubumbashi market, notably the Rail, Kaleja and Mpande markets which receive products from Likasi road and Kasenga road, and the Matshipisha market which receives products from Kipushi, Sodimico and Kaponda “chefferie” (a rural county ruled by a traditional chief) on Kasumbalesa road, stem from the forest or the bush. They allowed us to distinguish different socio-professional groups whose roles are, among others, to be used as food, furniture manufacturing, wood frame/timberwork, building structure, sculpture, art works, manufacturing of coffins/caskets, drums, fishing pirogues, royal power signs, etc. Investigation was conducted through interview of target groups. Most questions asked to the surveyed people were open because we needed their opinion and that is why certain terms and/or names of some trees, insects, birds and other animals were written down in their own language or dialect. To that effect, of all the very important trees in the province Sanga, Yeke, Chokwe tribes, etc. (according to the given socio-cultural importance), the only tree (the “Mwemwe tuseko”: *Sterculia quinqueloba*) of which our guides remembered again the location was photographed. The sample was randomly taken. A total of 295 people were questioned. Among them were 15 antelope hunters, 20 sellers of various woods, 80 embers’ sellers, 40 wild duck sellers, 30 wood furniture

Table 1 Questioned people per socio-professional category and quantity sold per working day each week.

Socio-professional category of questioned people	Number of sellers	Quantity sold per week						Total
		Mon	Tue	Wed	Thu	Fri	Sat	
Antelope hunters	15	4	2	0	1	2	7	16
Wood sellers	20	500	600	650	700	550	600	3,600
Ember sellers	80	30	90	70	30	90	70	380
Kanga (Wild duck) sellers	40	2	4	5	1	4	6	22
Wood furniture sellers	30	5	4	3	5	6	2	25
Straw mat (per m^2) sellers	5	12	14	10	16	20	15	87
Goose sellers	40	13	17	25	30	15	20	120
Other birds' sellers	10	20	15	25	20	10	30	120
Pigeon and Guinea fowl sellers	40	50	45	40	20	30	45	230
Catfish and tilapia sellers	15	25	30	27	15	33	45	175
Total	295	661	821	855	838	760	840	4,775

sellers, 5 straw mat sellers, 40 goose and Guinea fowl sellers, 10 gosling sellers, 40 green pigeon sellers and 15 catfish and tilapia sellers (Table 1). In the same order, certain photographs taken with a Huawei Honor smartphone and a DN6JNAS4DKNV iPad are shown.

3. Results and Discussion

3.1 The Role and Importance of Trees and Animals in the Cultural Life of the Population of Upper-Katanga

The statistics of provincial inspection of public health in Lubumbashi city show that during 2002 in Kampemba, Lubumbashi and Ruashi communes, there were in total 100,507 cases of malaria, 10,591 cases of acute respiratory infections, 10,389 cases of diarrhoeic diseases (9,604 cases of simple diarrhea and 785 cases of bleeding diarrhea) and 5,826 cases of STI (Sexually Transmissible Infections). Those were the most frequent diseases in the Lubumbashi sanitary district.

To fight against that curse which decimates the population, mostly the poorest, people have to organize themselves according to their region in order to take care of themselves. The bad socio-economic situation faced by developing countries, particularly the DRC (Democratic Republic of Congo), pushes patients to resort to traditional medicine. One of the recent WHO (World Health Organization) reports indicates that 80% of the world population use natural products, particularly plants to treat himself. Indeed, the traditional medicine resorts to the use of natural products of which the main sources are plants, mushrooms, animals and mineral products [7]. In the Lubumbashi region, traditherapists (traditional therapists) use plants to treat sickle cell anaemia and other various diseases [8].

Medicinal plants occupy a place of choice in the treatment of different pathologies. That reality is mainly observed in developing countries due to several reasons, including the completely deteriorated socio-economic situation, the extreme poverty of the majority of the populations, and cultural considerations [9].

The "biomedicine" does not take into consideration the somatic dimension of the illness whereas the traditional medicine takes care of the somatic as well as the psychic dimensions (a man is considered as a bio-psycho-socio-cultural constituent) [9].

According to the belief of the population in Upper-Katanga province, certain trees and animals present a great socio-cultural importance in the life. That is notably the case of:

(a) The "*Mwemwe tuseko*" (*Sterculia quinqueloba*), a white tree of which roots serve to provide chance and good evolution in professional life (Fig. 1).

(b) The "*Mutakali*", a tree of which trunk and branches are utilized as the pillars on which the drums

Fig. 1 The Mwemwe tuseko (Sterculia quinqueloba).

Fig. 2a The *Mutakali*.

Fig. 2b The *Mutakali*.

of the Yeke tribe kingdom are hanged (Fig. 2a), the same "*Mutakali*" also used for manufacturing small chairs on which the king and the queen seat down during different rituals (Fig. 2b).

(c) The "*Nkota bagoli*", a tree which is among the constraints/tabous in the Yeke tribe and of which, for instance, it is forbidden to the queens to burn for warming themselves up.

(d) The "*Mulwalwa*", a tree of which the roots are often abusively used for separating couples; it means that it is only enough that the roots of this tree be thrown to the roof of a house to note/observe later on the breaking up of the couple who was living in the house.

(e) The "*Mubanga*" (*Pericopsis angolensis*), another tree of which roots and leaves are soaked in bath water by mothers of young children (boys) for their boys to become strong during their childhood.

(f) The "*Ndulwe kyulu*", a tree of which bitter roots are used for causing abortions.

(g) The "*Mutondo*" (*Julbernadia paniculata*), a tree economically good for charcoal-burners as its trunk and branches also produce charcoal.

(h) "*Musamba*" (*Brachystegia wangemeeana* or *Brachystegia boehmii*), a tree of which bark is used as a rope to tie up/to link together hunters' burdens.

(i) The "*Mulombwa*" (*Pterocarpus angolensis*), an economically important tree because of the quality of its wood which is appreciated by joiners. The "*Mulombwa*" produces a hard and beautiful wood, two qualities economically profitable for the joiners as the furniture made from that tree, and attracts customers because of the wood qualities.

(j) "*Lion*", a very important animal in the Bayeke tribe as it represents the life of the king, and the Bayeke chief is considered as a lion. The skin of the animal serves as a carpet on which the king puts/places his feet onto the main courtyard. The lion tail symbolizes the power of the king (Fig. 3).

(k) "*Pangolin*", a mammal animal which is not consumed as it causes the kwashiorkor (a malnutrition illness due to protein deficiency) to children, according to the tradition of "Bajila-Kasanga", a tribe of the Central Kasaï province. That tribe forms almost 10% of the population of the Upper-Katanga province.

Since a long time, certain collectivities protect such or such trees because those trees are used as rallying point or because they assume a sacred character.

Fig. 3 A lion tail in the hands of the Bayeke chief.

3.2 The Role and Importance of Forest in the Economic Life of the Population of the Upper-Katanga Province

Economically speaking, biodiversity occupies a great place in the life of the Upper-Katanga population, especially that biodiversity provides the population with many things such as wood for building houses, wood for charcoal/ember making and for charcoal-fired heating in rural area (Fig. 4). The embers constitute more than 80% of energy consumption by the Upper-Katanga population, they are packed in 50-kg bags (Fig. 5a). They are ignited with ember igniters (Fig. 5b).

Wood is also used for making house equipment such as furniture (Fig. 6a), mixers and mortars (Fig. 6b). Moreover, biodiversity also provides households with food and financial resources through the sale of biodiversity products, etc. The strongest dependence toward wood energy is observed in Sub-Saharan African countries where 93% of the rural population and 58% of the urban population depend on biomass (such as wood for fire, embers, agricultural waste, animal feces) for combustible [10].

Fig. 4 Construction trees for sale.

Fig. 5a 50-kg bags of embers for sale.

Fig. 5b Ember igniters for sale.

Fig. 6a Wood furniture for sale.

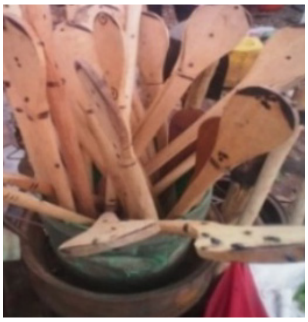

Fig. 6b Mixers for sale in a mortar for sale, too.

Practically, the food offered to the Upper-Katanga households by the biodiversity concerns notably the antelope that is one of the most consumed meat in the province. It is followed by the goose, the wild duck (also called "Kanga"), the Guinea fowl, the green pigeon, the catfish and the tilapia. Those species of which local demand is considerable represent a very high level of hunting and fishing in the province (Figs. 7a-7d).

The commercial hunting has a long history which started with the Belgian colonization and continued without breaking off but with different actors up to now. The hunting is concerned with small and medium-sized fauna which presents natural dynamics of very high reproduction and which withstands well high hunting pressure [5]. The venison, especially the smoked meat, plays an important role in the food security for the rural and the poorest urban people. Hunting for meat is not with free access but the network is strongly regulated

Fig. 7a Guinea fowls and green pigeons alive in a wire-mesh cage and smoked Guinea fowls above the cage.

Fig. 7b Tilapia fish in two small baskets.

Fig. 7c Catfish hanged with a rope by a seller.

Fig. 7d A wild duck in the right hand of a seller.

by social, economic, geographic and technical constraints [5]. Besides, one can also find in the pots of the Upper-Katanga population the "*Maninshi*" which are termites having the form of small wasps. They go out of termite mounds at the first great rainfall of the season. They are directly captured under sieve when they go out of their small holes or on tree leaves placed around the holes and on which they climb before flying away. The "*Malomba*" are termites going out of holes of termite mounds where they are captured at night using paraffin lamps/hurricane-lamps or any other luminous means in rainy season. The "*Malomba*" in Kisanga dialect are called "*Inswa*" in Kiswahili.

Rats are captured in the bush or in the fields before, during or after harvesting using traps which are called "*Biriba*" in Kisanga. The "*Nseshi*" are reed rats that often live on the river banks or in humid places. They are captured by hunting dogs often during the dry season, from the end of April to October.

The "*Nzobe*" are antelopes of large size which live in humid places. They are often hunted in dry season and rarely/seldom in rainy season. One can hunt them alone but they are often hunted by group of hunters who use hunting dogs and also by using traps made of copper wires called "*Sambo*".

Edible caterpillars, that are part of the main non-agricultural products, are strongly consumed in the Upper-Katanga province.

Secondly, financial resources are guaranteed through selling of the cited products or species drawn from the biodiversity to satisfy other needs that would not be satisfied otherwise (Tables 1-3; Figs. 8-20).

The budget of the Upper-Katanga province is made/constituted of 80% of mining exploitation/activities but the main activities in the province are notably the small trade that occupies the first place (50%), followed by industrial and artisanal mining activities (25%), then urban and peri-urban truck gardening (22%), and farming (3%). Agriculture, small trade and faming together account for 19.9% in the province budget. The biodiversity products encountered on the social, cultural, economic and sanitary markets constitute a small portion in terms of contribution to the budget of the province, especially that those products are illicit. This means that the trees and animals are clandestinely cut or killed and that is why no reforestation is done after deforestation. It is only from sanitary service offered by traditherapists at the level

Table 2 Embers production with a frequency of twice a week.

Category	Charcoal	Quantity	PU (in CDF)	TP (in CDF)	TP (in USD*)
Furnace (Kibiri)	4 trees (furnace of 3 m long × 2 m wide × 2 m high)	30 bags	9,000	270,000	163.64
	12 trees (furnace of 10 m long × 5 m wide × 2 m high)	90 bags	9,000	810,000	490.91
Tree field of 50 m long × 25 m wide for a charcoal furnace	Furnace of 8 m long × 4 m wide × 2 m high	70 bags	9,000	630,000	381.82
Total	16 trees and a charcoal field of 50 m × 25 m	190 bags	9,000	1,710,000	1,036.37
Total multiplied by	a mean of 20 charcoal sellers per sale point	3,800 bags	9,000	34,200,000	20,727.27

CDF: Congolese franc; PU: price per unit; TP: total price; USD: United States of America dollar; * 1 USD = 1,650 CDF.

Table 3 Types of animals sold at the market.

Animal type	Quantity	Price (in CDF)	Quantity	Price (in CDF)	Price (in USD*)
Antelope	1 portion	30,000	1×4 portions	120,000	72.73
Kanga (Wild duck)	2 portions	50,000	2×2 portions	100,000	60.61
Goose	1	65,000	1	65,000	39.39
Pigeon	1	5,500	1	5,500	3.33
Guinea fowl	1	25,000	1	25,000	15.15
Catfish	1	5,000	1	5,000	3.03
Tilapia	1 straw basin	5,000	1	5,000	3.03

CDF: Congolese franc; USD: United States of America dollar; * 1 USD = 1,650 CDF.

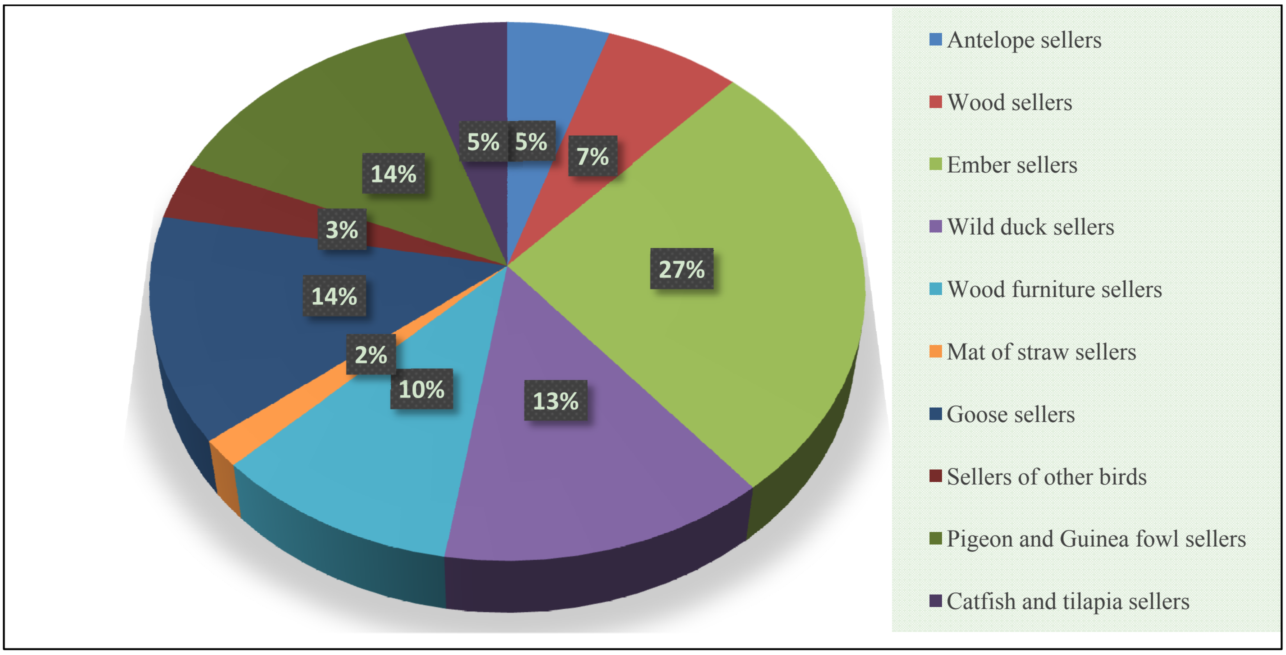

Fig. 8 Surveyed people per socio-professional category.

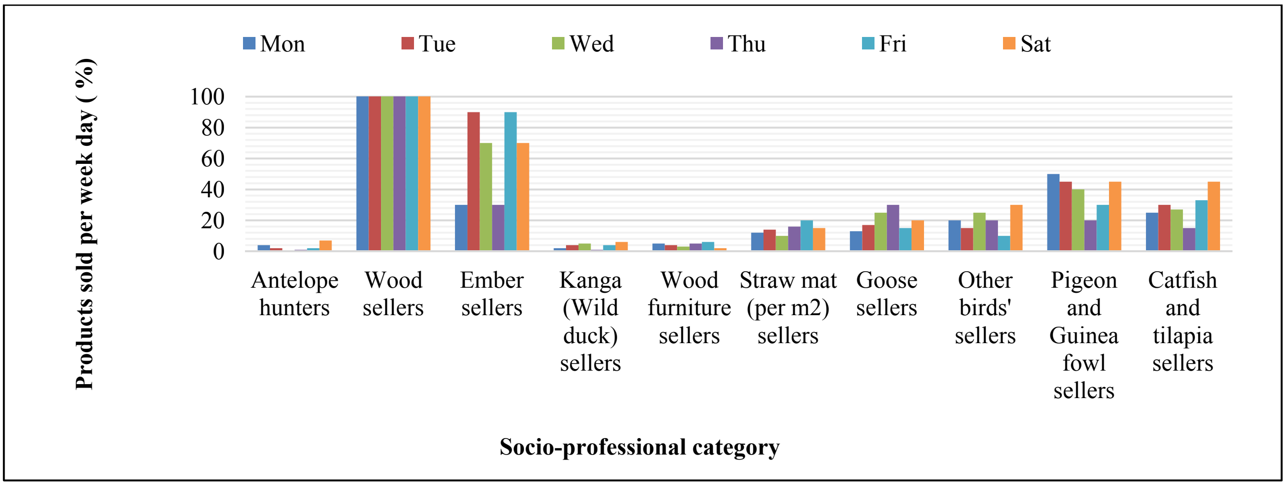

Fig. 9 Frequency of product sale per socio-professional category.

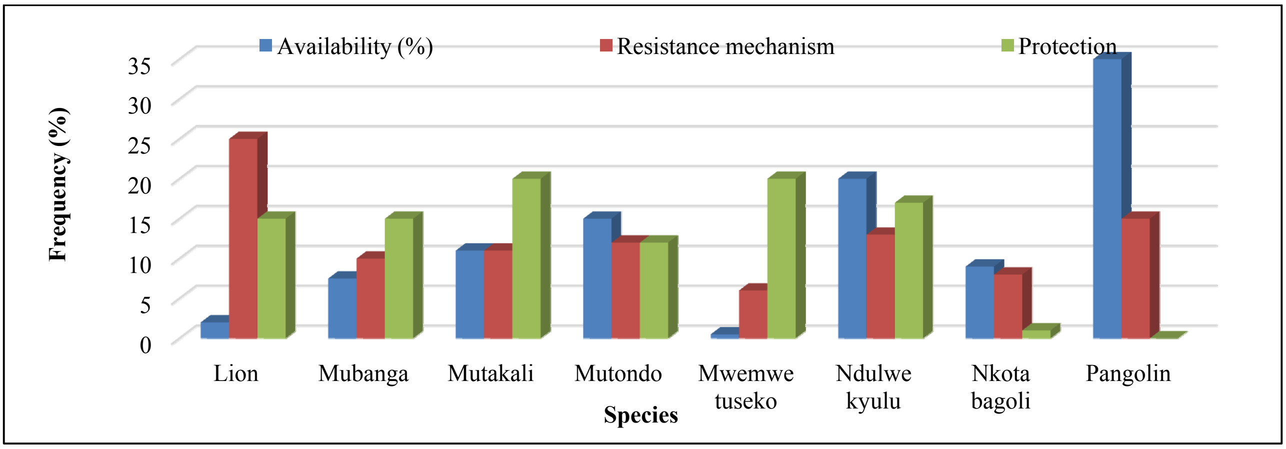

Fig. 10 The socio-cultural role and importance of biodiversity.

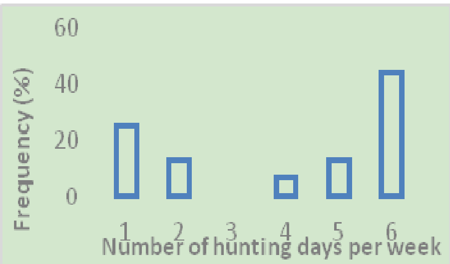

Fig. 11 Frequency of antelope hunting days per week.

Fig. 13 Frequency of embers sale days per week.

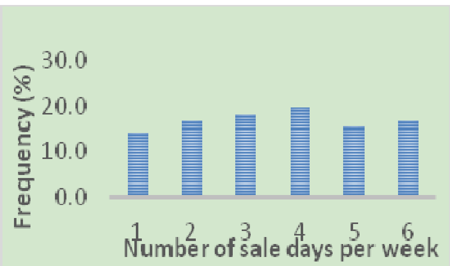

Fig. 12 Frequency of wood sale days per week.

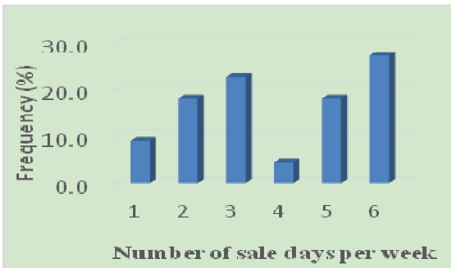

Fig. 14 Frequency of wild duck sale days per week.

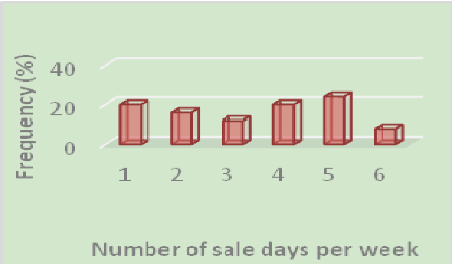

Fig. 15 Frequency of wood furniture sale days per week.

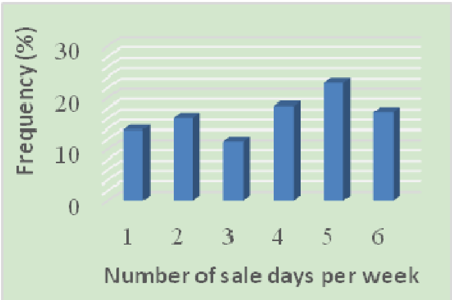

Fig. 16 Frequency of straw mats (per m^2) sale days per week.

Fig. 17 Frequency of goose sale days per week.

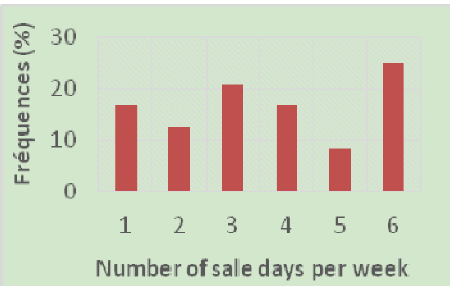

Fig. 18 Frequency of gosling sale days per week.

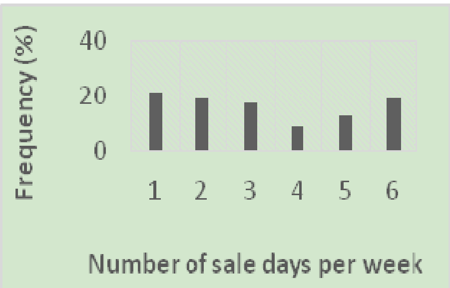

Fig. 19 Frequency of green pigeon sale days per week.

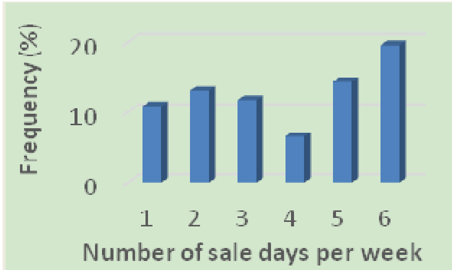

Fig. 20 Frequency of catfish and tilapia sale days per week.

of 95% and whose actors are required to pay for administration and other expenses necessary for the functioning of the province.

4. Conclusion

The biodiversity and forest play various important roles in the life of the Upper-Katanga population. This study brings light to different spheres of the daily life of the same population through the trees and animals they utilize under cultural, economic and social forms. On one side, the trees are culturally used in the king's yard, for breaking up couples, for causing abortion and, on the other side, in an economic manner by constituting financial resources through selling charcoal/embers (wood energy), wood for construction and wood for making furniture. Various plants and mushrooms are used by tradition medicine to treat different diseases. Animals too are utilized in the same cultural and economic contexts. The lion tail and skin are considered as a source of authority and power for the king. The hunted and captured animals are consumed or sold by the population. The importance, more economic at 99.99% than socio-cultural (0.01%), given to those species pushes to an overexploitation which threatens those animals with extinction.

Acknowledgements

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The Contingent Valuation Method in Excavation/Preservation the Ancient Eleusinian Sacred Way in Greece

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Abstract: The aim of this study is to estimate externalities created round a cultural heritage preservation site. A research was conducted concerning the ruins of an ancient 'Sacred Way' (Iera Odos) located in Attica, Greece. The sample of the research was 200 citizens (interviewees). It is used the CVM (Contingent Valuation Method) and Logit model of the regression analysis. The preservation of cultural heritage is entailing excessive cost (paid by people through taxation) while is a source of additional income for both, the State and the people, due to tourism. Since the evaluation of this good cannot be in market terms, authors apply a modified version of the CVM (Contingent Valuation Method). The findings show there is strong evidence that at the 5% significance level, WTP (against WTA) is a better preferred course of action i.e., leaving the ruins situation as it is, performing only the necessary remediation, proceeding with radical restoration. All statistical processing of answers, obtained through a properly designed/circulated questionnaire, was carried out by Logit model regression analysis. The model gave significant (at 0.05 levels) dependence of WTP_{ar} (Willingness to Participation) on preferred course of action (i.e., leaving the ruins situation as is, performing only the necessary remediation, proceeding with radical restoration).

Key words: WTP, WTP_{ar}, externalities, cultural heritage, sacred way.

1. Introduction

Cultural heritage usually refers to the monumental remains that have been inherited from past generations to present society, which will hopefully take care of them for sake of the future generations. Moreover, the concept of cultural heritage has gradually enriched by including intangibles as well as ethnographic or industrial knowledge/know-how of the past. On the other hand, the works of both categories, art and everyday living in the community of the past, include (or/and refer to) political, socioeconomic, intellectual, philosophical or religious considerations. Since the preservation of cultural heritage, and especially of the monumental ruins, is entailing excessive cost (paid by people through taxation) while is a source of additional income for both, the State and the people, there is an increased interest for evaluating this non-marketable good.

The economic valuation of cultural heritage constitutes a scientific challenge since most studies estimate its economic effect as an external benefit or as a source of tourist attraction. The first application of the CVM (Contingent Valuation Method) in the field of cultural goods dates back to the 1980s [1]. Since there many studies in literature [1-3] applied and validated the CVM as a technique of the recently established scientific field of Experimental Economics. Several researchers applied CVM in many scientific fields such as historical buildings [2], museums [3, 4], archaeological sites [5], tourism economics [5, 6] and cultural goods [7]. CVM is basically subjective, attempting to acquire objectivity by extracting attitude and information from a stratified representative

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sample of interviewees, who are asked by means of a questionnaire to assign a value on a non-marketable (e.g., cultural or environ-mental, like a monument or a forest respectively) good or an externality (considered as ‘transaction spillover’ by *laissez-faire* economists like Milton Friedman and Friedrich Hayek) [7].

The evaluation of a benefit or a cost is not related to market values. The aim of the CVM is both to create a hypothetical market in which participants may state their maximum WTP (Willingness to Pay) for a variation of a good through answers of the questionnaires or to correspond to the minimum monetary amount which an individual would accept as compensation in order to relinquish this public good/service—WTA (Willingness to Accept) [8].

However, what happens if the interviewees are not asked to pay or to accept monetary units but are asked for voluntary work? The main answer which a researcher has to extract from questionnaires is the high of the opportunity cost of a day of a voluntary work for every single participant. Actually, the interviewees are asked for voluntary participation in a restoration of a monument of cultural heritage. The CVM (Contingent Valuation Method) is a survey—based technique, frequently used in Experimental Economics, especially useful for the valuation of non-market resources/goods/services, and cultural heritage objects (of aesthetic, historic, scientific or social value), such as conservation of monumental remains and preservation of the physical and anthropogenic environment.

This approach measures the maximum time which volunteers are willing to spend. So, this study is not a formal application of WTP method but it’s actually a ‘Willingness to Participate’ research (WTP_{ar}) due to asking for voluntary work. According to above considerations, this study has the following structure. Section 2 contains a short historical review of the studying ancient monument called ‘Sacred Way’. The methodology of the study is analyzed in section 3. Section 4 contains the empirical results of our study and the comparison with a previous study about the excavation of the ancient theatre of Lefkada island in Greece. Last but not least, in section 5 conclusions and proposals for further study are mentioned.The ancient Sacred Way is shown in Fig. 1.

2. ‘Sacred Way’ (Iera Odos) through time

The Sacred Way is the most ancient road in Greece. However, its emergence as a monument of classical antiquity with its corresponding historical value has not progressed. For 2,500 years, it remained the only national road connecting Athens with Northern Greece, Epirus and the Peloponnese. Its construction with infrastructure and asphalt was made in 1927. Since then it has the same form, with the only differentiation some widening. No other access to Athens existed until 1956, when the Avenue of Athens was built, which is located at the Holy Trinity at the height of the Daphni Monastery. The frame of Sacred Way is observed in Fig. 1.

The Sacred Way was in the ancient times the road connecting the city of Athens with Eleusis and Thriassius Pedio, where once a year were the famous (but still inexplicable about their exact character) Eleusinian mysteries. It was 22 km long, starting from the Holy Gate in the Kerameikos area, near Dipylos. Most of it followed the course of today’s Sacred Way, crossing the area between the Mount Aegaleo and the Poikilos Oros, ending at the sanctuary of Demeter in

Fig. 1 The ancient sacred way.

Eleusina. In antiquity, any road linking the city with a regional sanctuary used to be called the 'Sacred Way'. The Athenian ancient Sacred Street is allegedly named 'Eleusinian'.

3. Methodology

During the last three decades, there has been growing interest in developing methods for assessing the preferences (of experts, stake holders, community/organization members, independent individuals) for environmental quality. Among them, the CVM (Contingent Valuation Method) is frequently applied to: (i) economic valuation of environmental projects or works/activities (planned or in operation) with a significant environmental impact and (ii) damage assessment after environmental accidents, i.e., after incidents that deteriorate environmental quality. This method is heavily relied on survey-based estimation of: (i) WTP (Willingness to Pay), which is the maximum amount of money that an interviewee would be willing to pay, sacrifice or exchange for a good, and (ii) WTA (Willingness to Accept), which is the minimum amount of money a person would be willing to accept in order to abandon a good. WTP is bounded by income while WTA is potentially unlimited. Whether WTP or WTA is appropriate, depends on the prior distribution of property rights and the direction of change under consideration.

In this work, it is considered the monuments of cultural heritage as a public good and the pollution as an external cost.

Consider an interviewee who formulates his WTP or WTA facing a trading opportunity in an experiment, knowing that the same good can be traded in the marketplace. To add structure, assume that an WTP (WTA) interviewee is one who must state a WTP (WTA) value in an incentive compatible institution. Let v be interviewee's own (uncertain) valuation of the public good, and let R be interviewee' s information about the market price of the good. That is, the interviewee does not know v or R with certainty, but knows their distributions. For simplicity, it is assumed that the interviewee can learn both v and R with certainty later (e.g., after the experiment). The personal willingness to pay is a function of the interviewee's own valuation about the good, v and his information about the same good, R.

$$WTP = F(v, R, d_1) \quad (1)$$

Where: d_1 denotes a group of other deterministic variables which can affect the WTP, like age, education level, etc..

Interviewee's valuation about the good v is directly affected by the opportunity cost of the monetary units OC_M.

$$v = F(OC_M, d_2) \quad (2)$$

Where: d_2 denotes a group of other deterministic variables which can affect v.

A combination of Eqs. (1) and (2) will lead to the fact that willingness to pay is a function of OC_M, R and other deterministic parameters with the Eq. (3):

$$WTP = F(OC_M, R, d) \quad (3)$$

Where: $d = d_1 + d_2$.

By asking the interviewees for their *'Willingness to Participate - $WTPar$ '* in the restoration of the archaeological site, it is tried to measure the willingness for voluntary participation. So, the $WTPar$ function has the following form *ceteris paribus.*

$$WTPar = F(OC_T, R, d) \quad (4)$$

In order to estimate the Eq. (4), authors use a Logit model which has the Eq. (5):

$$f(z) = \frac{e^z}{e^z + 1} = \frac{1}{1 + e^{-z}} \quad (5)$$

Where: the variable z is usually defined as $z = \beta_0 + \beta_1 X_1 + \cdots + \beta_k X_k$, while β_0 is the constant term of the regression and $\beta_1, \ldots, \beta_k$ are the regression coefficients of $X_1, \ldots, X_k$, respectively. The independent variables $X_j, j = 1,2, \ldots ,8$ stand for respondents' income, age, living distance from the monument, real estate ownership in the vicinity, membership in organization with cultural activities (volunteering), extent to which the interviewee is informed about the history of the site (information), coming in the site as visitors/tourists before (previous visit) and education level, respectively.

It is also examined the affect of information to $WTPar$, *ceteris paribus.* It is applied a Kolomogorov—Smirnov test to secure that our data are normally distributed and then we applied a t −test for dependent sample to compare means. In last step of this study, it is compared $WTPar$ of the interviewees of the present study against the interviewees of a similar study to examine the effect of opportunity cost of their time and information at the same time.

In order to collect the data for this survey, we get a random sample of 100 Greek citizens (interviewees) of the city of Eleusis in Attica and ask them to complete a questionnaire before they get informed about the history of the Sacred Way and the same questionnaire after they read an attached informative text.

4. Results

In the first part of empirical analysis of data, which were lured from questionnaires, there is the analysis of variance (AN.O.VA.) and the logit regression analysis. In the second part, we create two new variables WTP_{ar1}, WTP_{ar2}. WTP_{ar1} represents the interviewees' willingness to participate to the restoration of the monument before they get informed in it. Following the first response, an informative text about the history of the monument was distributed to interviewees and they were asked about their willingness to participate again (WTP_{ar2}).

On the one hand of analysis it is created the WTP_{ar} regression which has the Eq. (5):

$$WTPar = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + b_8X_8 + u \quad (6)$$

Where: $X_1, \ldots, X_8$ represent the independent variables which were determined in section 3.

On the other hand, it is examined the influence of the independent variables to the dependent one as a group, using the AN.O.VA. approach (Table 1).

The F −statistic was found equal to 58.147 and also, statistically significant to the 5% significance level (while the $p-$ value is equal to 0.001). According to this result, it is assumed that this model is well-structure and the independent variables are appropriate to determine the behavior of the dependent variable.

It is estimated the Eq. (6) using a logit model analysis. The results of the regression can be seen in Table 2.

The estimated expression of Eq.(6) has the Eq. (7):

$$WTPar = 70.2 - 0.015X_1 + 0.018X_2 + 0.040X_3 + 0.016X_4 + 0.039X_5 + 0.032X_6 + 0.024X_7 + 0.062X_8 \quad (7)$$

As it is observed in Table 2 and Eq. (7), all variables have a statistically significant effect to the $WTPar$ variable. It is shown that volunteering, age, living distance, ownership, information, previous visit and education level have a positive influence to the interviewees' willingness to participate to the excavation/restoration of 'Sacred Way', while the income effect to same variable seems to be negative. Despite the fact that the effect of each variable seems to be low enough to change the maximum time of voluntary supply work of interviewees on its own, the

Table 1 Analysis of variance for dependent variable WTP_{ar} (AN.O.VA).

Source of variance	Sum of squares	df	Average sum of squares	**F** −statistic (**p** −value)
Regression	58.532	6	8.063	
Residuals	12.354	68	0.115	58.147
Total	62.854	91	−	(0.001)*

Table 2 Coefficients of logit regression.

Variable	Coefficient ($\boldsymbol{p}$ −value)
Income	-0.015 (0.008)*
Age	0.018 (0.037)*
Living Distance	0.040 (0.018)*
Ownership	0.016 (0.022)*
Volunteering	0.039 (0.007)*
Information	0.032 (0.000)*
Previous Visit	0.024 (0.014)*
Education Level	0.062 (0.002)*

Note: (*) denotes statistical significance at 5%.

Table 3 Descriptive Statistics for $WTPar1, WTPar2$.

Variable	N	Mean	SD	SE Mean	Min	Max
WTPar1	100	1.52	1.821	0.132	0.00	15.00
WTPar2	100	5.20	3.518	0.567	1.00	19.00

aggregate effect of all variables seems to be able to cause a statistically significant change on $WTPar$ time of interviewees.

It is created the WTP_{ar1} and WTP_{ar2} according to the procedure which was analyzed at the beginning of section 4. The descriptive statistics of these two variables can be observed in Table 3.

The mean of $WTPar1$ is equal to 1.52, while the mean of $WTPar2$ is more than three times higher and equal to 5.20. This result can also be visualized by the bar-chart. It is supposed that there is a significant difference between these variables. To validate this indication, it is provided a test to compare the means of $WTPar1$ and $WTPar2$ time of interviewees before and after they get informed about 'Sacred Way' monument. To choose a proper parametric or non-parametric test it is applied a Kolmogorv-Smirnov test in order to examine if these data are normally distributed. The test was positive, so it is chosen a t −test for dependent samples to compare means of $WTPar1$ and $WTPar2$ (Table 4).

In a previous survey, a sample of 100 interviewees was selected and their willingness to participate in the excavation of the ancient theatre of Lefkada Island in Greece is measured before and after a reading of an informative text about this monument (Table 5).

The important effect of opportunity cost in WTP_{ar} is obvious according to the above descriptive statistics. The interviewees with high opportunity cost are able to spend an average of half a day to the restoration of the monument against an average of 1.5 day by the interviewees with low opportunity cost of labor before information. A significant increase of these averages can be observed after the information, with 5.23 days and 5.56 days respectively. To examine if there are significant differences between the WTP_{ar} of interviewees of each group, we provide a t-test for independent samples before and after information (Table 6).

In the Table 6, it is provided evidence for significant difference between WTP_{ar1} for each monument which declares that the existence of opportunity cost of labor effects the willingness of interviewees to participate in restoration of these cultural heritage monuments.

Table 4 t −test for paired samples.

Pair of variables	Mean	Standard deviation	t −statistic	p −value	Decision
WTP_{ar1} - WTP_{ar2}	−0.83	0.196	−59.132	0.000*	Significant difference before and after information

Table 5 Descriptive statistics of WTP_{ar} in ancient theatre of Lefkada.

WTP_{ar1}—Before information					
Monument	N	Mean	SD	Min	Max
Lefkada's theatre	100	0.50	1.451	0.00	6.00
WTP_{ar2} – After Information					
Lefkada's Theatre	100	4.13	2.899	1.00	9.00

Table 6 t-test for independent samples for WTP_{ar} for two monuments before and after information.

Before information					
Pair of Variables	Mean	Standard deviation	t −statistic	p −value	Decision
WTP_{ar1} (Theatre) - WTP_{ar1} (Sacred Way)	−1.00	0.528	−19.116	0.001*	Significant difference
After Information					
WTP_{ar2} (Theatre) - WTP_{ar2} (Sacred Way)	−0.51	0.039	0.912	0.486	No significant difference

5. Discussion

This study is trying to examine the willingness of interviewees to voluntary participate to the restoration of an ancient Greek monument called 'Sacred Way '. The research took place with filling of questionnaires by 100 randomly selected interviewees of the city of Eleusis in Attica. The questionnaires were filling two times by each interviewee, one time before he is able to read and informative text about 'Sacred Way' and after the reading of the text.

The interviewees' willingness to participate to the excavation/restoration of 'Sacred Way' is influenced by several parameters, as it comes of the analysis. Specifically, income, age, educational level, living distance, ownership, volunteering, information and previous visiting affect the willingness to participate. The interviewees with higher education level show a greater willingness to participate than those with lower education level. The older the interviewee is, the greater willingness to participate he has. The distance of permanent residence from the monument, the previous visits to the monument and the ownership of any kind of land around the monument have a positive influence to the willingness of interviewees. An extremely interesting result is the positive effect of information to the interviewees' willingness. There is a huge increase of their willingness after they got informed about the history of 'Sacred Way'. The negative income effect to the interviewees' willingness to participate is another interesting result of our analysis (Table 5).

The fact of negative income effect is explained through the refusing of interviewees with higher family income to participate to the restoration of 'Sacred Way'. It is a common knowledge that the higher income an interviewee has, the less sensitivity for public goods has. This statement derives from the preference of these interviewees to the evolution of the private market against the public sector. An absolute opposite effect to the willingness to participate derives from the previous volunteering and information. An interviewee with previous volunteering activity seems to be more sensitive to take care of cultural heritage monuments.

The awareness of these interviewees about the level of usefulness of voluntary work tends them to always trying to offer more and more voluntary work. An extremely interesting and positive effect to the willingness is coming from the information of the participants. The more information that an interviewee has about a monument the higher willingness he has to participate to its restoration.

In a previous study of one of the authors, the willingness of interviewees to participate in the restoration of the ancient theatre of Lefkada Island in Greece was measured by common method. The alert difference between these two studies is the existence of opportunity cost in the first study and absents of same cost in the other. The comparison of results of these studies will declare the importance of opportunity cost to the willingness of people to participate in volunteering work.

According to the study of ancient theatre of Lefkada Island, the 58% of interviewees have previously volunteered in similar work, whereas 42% have not, the 36% of the interviewees have visited the site, while 64% have not, the 31.5%, 41% and 27.5% of the interviewees were aged between 18-22, 23-47 and 28-31 years old, respectively. The 3%, 22%, 31.5%, 22% and 21.5% of the interviewees have completed primary school, high school (1-3 class), high school (4-6 class), university or technological institution or postgraduate studies respectively.

The difference between the willingness to participate to voluntary work seems to be higher before the reading of the informative text by interviewees. The first part of the result is the fact that the existence of opportunity cost decreases the willingness to voluntary work. The second part is the increase of willingness to voluntary work after the interviewees get informed about the monument. The opportunity cost effect is eliminated by the information effect. This fact is an evidence of general sensitivity of Greeks to the restoration of cultural heritage monuments.

6. Conclusion

The output of the WTP approach is the demand curve of a non-marketable good. Our methodological modification leads us to extract a supply curve of voluntary work. This fact is extremely interesting but also a bit simple because the participants have no opportunity cost neither they get paid for their military services. Moreover there is not a transportation cost, because the interviewees are located *in situ*. This method can be more complicated by inserting opportunity cost of time and transportation cost of the volunteers. This add-ins can make this method more efficient due to using to many more groups of citizens.

The depreciation of antiquities caused by humans is an external economy, which is not corrected through any institution or market, if not intervene in politics. From the statistical analysis we see a path to stabilize the social costs of depreciation of cultural goods. External effects are observed when supply or demand impose costs or confer a benefit to others. More specifically, the external effect is the impact of the behaviour of a producer or consumer well-being of another, which is not reflected in market transactions. The external effect of the deterioration of cultural monuments is universal and appears as an external benefit borne by all of humanity through time.

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