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ARTICLE

Remineralization of a Dystric Ferralsol Using Basalt and Tephra Dusts, Effective Microorganisms Manure and NPK 20-10-10 for Radish (*Raphanus sativus*) Production in Bamougoum (Cameroon Western Highlands)

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ABSTRACT

This paper studies the effect of basalt and tephra dusts, as alternatives to chemical fertilizers, on soil fertility and Radish (*Raphanus sativus*) production. The experiment was conducted in the field and in the laboratory in the years 2017 and 2018 on two separate plots so as to annul residual effects of fertilizers). The experimental design in the field was a randomized complete block design (56 m^2), including five treatments and three replications: control (T_0), basalt dust (T_1), tephra dust (T_2), effective micro-organism (EM) fertilizer (T_3) and NPK 20-10-10 (T_4). The main results show the following decreasing trend based on yield: $T_1>T_3>T_0>T_4>T_2$. The best yields appear in T_1 and T_3 probably because they supplied the highest levels of soil nutrients to match the needs of the crops. Although T_2 plants performed poorly, soil properties like $pH.H_2O$ (6.14 to 6.49), sum of exchangeable bases, base saturation, available phosphorus and cation balance were improved after tephra treatment. T_2 plants might have performed poorly due to intrinsic properties of the tephra dust like low availability of trace elements compared to T_1 and T_3. T_4 plants show the highest number of leaves, leaf area index and plant height. The Fe, Mn, Cu and Zn levels in bulbs and leaves will not pose danger of toxicity to human upon consumption and could serve as nutrient supplement for children and expectant mothers. The most profitable treatment is T_1 permitting to recommend the popularization of basalt dust for radish cultivation as an alternative to chemical fertilizers.

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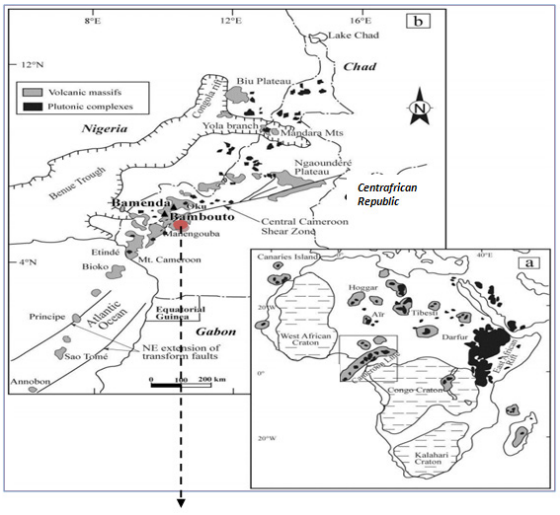
1. Introduction

Natural geologic materials are suitable for restoring soil fertility as alternatives to chemical fertilizers that instead destroy beneficial soil bacteria and pollute the environment [25,29]. The present state-of-knowledge on the use of rocks as fertilizers reveals that modern agricultural and agro-forestry practices often cause nutrient depletion in soils leading to nutrient deficiencies [12,35]. Soil remineralization is an economically and ecologically sustainable alternative to chemical fertilizers based on its capacity to regenerate nutrient depleted soils [21,24]. Rock dusts of volcanic origin like basalt and diabase are most recommended due to their high contents of silicon necessary for proper cell structure, and a well-balanced array of calcium, magnesium and micronutrients [15]. Crops grown on mineralized soils generally show higher vitamin and mineral salt contents, thus favouring better human health and resistance to diseases than those produced with synthetic fertilizers [22]. The use of rock dust to improve soil quality and crop yields has been reported [1,3,5,16,31]. In Cameroon, research activities on the use of rock dust as fertilizers remain timid. This might be explained by the lack of awareness on the use of rock dust for soil amendment despite large reserves of volcanic, sedimentary and metamorphic rocks in Cameroon. There is need for a detailed investigation of rock dusts as soil amenders for crop production. Recently, measurements by [3,16] revealed many advantages of rock dusts compared to chemical fertilizers : they are environmentally friendly and crops grown with rock dusts usually show higher resistance to disease, and higher levels of vitamins and micronutrients [3,31]. Their exploitation is relatively cheap and the only expenses come from excavation, loading, transportation and crushing into power form. Various types of volcanic rocks are abundant along the Cameroon Volcanic Line [31]. These rocks are highly demanded as building material and road construction. Most farmers are not aware of the use of these materials as fertilizers but rather resort to chemical fertilizers. Soils are regularly been fertilized with chemical fertilizers often causing soil acidification and destruction of soils organisms [15]. Very few scientific works have also been dedicated to rocks as fertilisers [4,10,30]. These works have revealed the importance of basalt and pyroclasts as fertilizers to many crops but none of these findings have been dedicated to Radish (*R. Sativus*) cultivation; this crop is highly cultivated, demanded and lucrative in Cameroon as a source of vitamins and micronutrients [30]. Numerous questions remain without answers: what is the effect of basalt dust on the performance of Radish? What is the implication of rock dust on soil quality relative to mineral and organic fertilizers? What is the economic implication of rock dust treatment relative to chemical and organic fertilizers? What is the micronutrient level of edible parts (roots and leaves) of Radish cultivated with rock dusts? The aim of the present study was to examine the effects of basalt and tephra dusts as amenders of degraded soils on the growth, yield and micronutrient composition of *R. sativus*. The results obtained will supplement the available data on the use of natural geological materials as fertilizers for cultivation of crop in Cameroon and beyond.

2. Geographical and Geological Settings

The study site was selected in Bamougoum Sub-division (Cameroon Western Highlands), at longitude 10º21'00"-10º24'00" East, latitude 5º30'00"-5º32'00" North and a mean altitude of 1300 m (Figure 1). The mean annual rainfall is 1707.4 mm and the mean annual temperature is 21.5°C, typical of a Cameroon type equatorial climate. The relief is hilly and undulating, and ends down as deep U- and V-shaped valleys. River Mifi is the most important river in the study area that flows across the Bafoussam town and together with its tributaries forms a dendritic drainage pattern. The vegetation is tropical grassland (mostly shrubs, stunted trees, grasses on slopes and raffia bushes in valleys) strongly modified by human activities. The soils are mainly Ferralsols, with minor andosols and Gleysols. Although not very popular in Cameroon, Radish is a garden crop whose fast harvest cycle, high yield and lucrativeness have fostered its market gardening especially near major city markets like Yaoundé, Douala and Bafoussam. It is easily planted as a companion crop or intercrop between rows of the other vegetables. It is often planted on beds separating one plot from another. It is cultivated when all year round, but intensified in the dry season as it is more lucrative.



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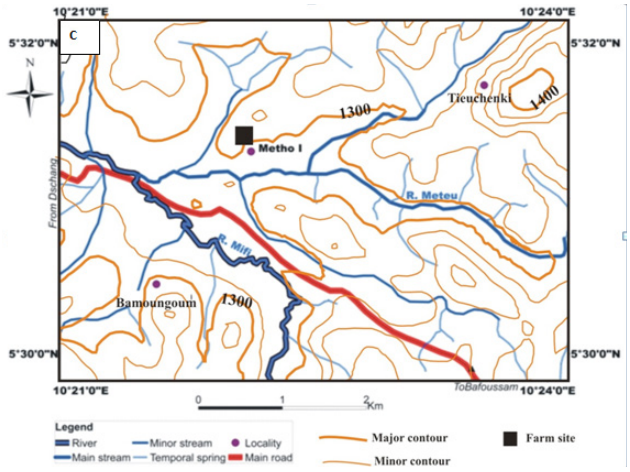

Figure 1. Location of the Cameroon Volcanic Line (CVL) and position of the studied site. (a) Location of CVL in Africa [6]; (b) Situation of CVL and studied site in Cameroon; (c) studied site in Bamougoum

The studied area is located along the Cameroon Volcanic Line (CVL). This CVL is divided into an oceanic and a continental sector [8]. Within the continental sector, the composition of the rocks range from picro-basalt and basalt through intermediate compositions to phonolite and rhyolite. Basanites, trachytes, tristanites, phonolites, basalt, nephelinites, tristankite and trachy-phonolites are found mostly in the oceanic sector. The Bamougoum area is composed mainly of basalt that overlies a granite-gneissic basement [6].

3. Methodology

The experiment was conducted in the field and in the laboratory in the year 2017, repeated in 2018. This was done on two separate plots so as to prevent the residual effects of fertilisers.

3.1 Land Preparation, Sample Collection and Pre-treatment

3.1.1 Sample Collection and Pre-treatment

The basalt and tephra were sampled in Bamougoum at latitude 05º30'25" N, longitude 10º23'17" E and altitude 1315 m for basalt, and at latitude 05º35'16" N, longitude 10º26'42" E and altitude 1307 m for tephra. The rock transformation to powders was done at Mbuy and Family Industry at Nkwen (Cameroon). Effective microorganisms manure (EM) was composed of microorganisms extracted from nature using Molasse carbon sources under anaerobic conditions at pH below 3 for seven days [28]. This involves a thorough mixture of rice husk and wheat brand using chlorine-free water, sugar solution and EM. The mixture was then put in a tightly closed plastic tank and left to ferment for seven days. Red skin variety of radish (*R. sativus*) seeds and granular NPK 20-10-10 fertilizer were bought in the Bafoussam Main market (Marché B). Soil samples for laboratory analysis were collected in two phases: after each treatment (BS) and after harvest (AH). The soil samples were dried, sieved, placed in labelled air-tight plastic bags and sent to the laboratory for analysis.

3.1.2 Land Preparation

In the field, an 8 m by 7 m plot was selected and ploughed on a Dystric Ferralsol, the most dominant soil type in the area. A randomized complete block design (RCBD) was used with five treatments (T_0 = Control soil, T_1 = basalt powder, T_2 = tephra dust, T_3 = effective microorganism manure (EM) and T_4 = NPK fertilizer 20-10-10) and three replications (T^I, T^{II} and T^{III}). Altogether, the plot was composed of 15 experimental units. The plot was then designed into three columns with each having five similar 2 m by 1 m ridges. The surfaces of the ridges were flattened and holes of 8 cm depth by 6 cm width were dug at 40 cm and filled with the rock dusts. The ridges were then watered daily for one month to permit to leach into soil. The basalt and tephra dusts were applied at a rate of 10 tons per hectare for optimum crop Radish performance according to [9]. The spotted areas were marked with sticks and soil samples were collected after one month for laboratory analyses. Sowing of the radish seeds was done on 20th April (first and second years of experimentation). EM manure was applied one week before sowing. The application of NPK 20-10-10 fertilizer on respective beds was done after two weeks of germination, with banding of the fertilizer 5 cm away from the radish stems. The EM manure and NPK 20-10-10 fertilizer were applied at the rate of 1 ton ha-1. In order to keep the soil porous and free from weeds, mulching was done twice, on the 20th and the 35th days after sowing. Harvesting was done on the 15th of June for each planting year.

3.2 Plant Data Collection

Ten radish plants were selected per experimental unit and data on growth parameters were collected on the 2nd, 4th and 6th weeks after planting. Thus, plant height was measured using a measuring tape. The leaf area index (LAI) was obtained as the product of leaf length (cm), leaf width (cm) and a constant (0.75) [18]. The number of leaves per plant was recorded. Six weeks after planting, the 10 bulbs per experimental unit were harvested and their weights were recorded using an electronic balance. The growth and yield parameters of each treatment were

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obtained as the mean of the three replicates of each treatment.

3.3 Laboratory Analysis

Laboratory work included petrographic, geochemical and physico-chemical analyses. Petrographic analysis involved the cutting of rock thin sections (basalt only since tephra was powdery in the field) at the Institute of Geologic and Mining Research (IRGM) in Yaoundé (Cameroon). The chemical analysis of rock powder was done in the "Laboratoire de Géochimie Appliquée" of "Université Technique de Berlin" (Germany). The major elements of basalts and were performed by Inductively Coupled Plasma-Atomic Emission Spectrometry ICP-AES meanwhile trace and rare earth elements were dosed by FI-ICP-Mass spectrometry. The loss on ignition (LOI) was determined by ignition of samples at 1050°C for two hours. Elemental contents were reported in %oxide for major elements and $mg.kg^{-1}$ for trace and REE. Relative errors are <3% for major elements and 5-10% for trace elements, except for Ni and Cr with a relative error of 15-20%. Relative errors of REEs are <10% for Sc and Y, and about 25% for Hf. The CIPW norm was calculated by assigning cations of major elements within the basalt to silica anions in the modal proportions to form solid solution minerals in the idealised mineral assemblage [4].

The physico-chemical and micronutrient analysis were performed in the Laboratory of Soil Analysis and Environmental Chemistry in the University of Dschang (Cameroon) according procedures reported by [37]. Thus, bulk density was determined using the paraffin method and the particle density was measured by pycnometer method. The soil porosity was deduced from bulk density and particle density. The particle size distribution was measured by Robinson´s pipette method. The $pH.H_2O$ was measured in a soil/water suspension of 1:2.5 using a glass pH-meter. Available phosphorus was determined by concentrated nitric acid reduction method. Exchangeable cations were analysed by ammonium acetate extraction method. Cation exchange capacity was measured by sodium saturation method.

Analysis of soil and plant micronutrients was done by total digestion method [10]. For soils, one composite sample of the control soil was analyzed. Thus, aliquots of 0.5 g of dried soil samples were digested with HNO_3 acid, H_2O_2 and HCl acid mixture in the ratio 5:1:1 at 80ºC until a clear solution was obtained. The solution was filtered with Whatman no. 42 filter paper and diluted to 50 ml with distilled water. The filtrates were analyzed for Fe Mn Cu Fe, Mn, Cu and Zn using atomic absorption spectrophotometry PG-900 Model, equipped with an air-acetylene flame and a hollow cathode lamp, under standard conditions using wavelengths and slit-widths specified for each element.

Dried crushed leaves and root (bulb) of beetroot were digested with HNO_3 acid, H_2O_2 and HCl acid mixture (5:1: ratio), filtered, diluted to 50 ml and then analyzed for Fe, Mn, Cu and Zn by atomic absorption spectrophotometry (PG-900 Model spectrometer) [10].

All soil and plant tissue samples were analyzed along with a blank solution. Calibration was performed with standard solutions while precision and accuracy were controlled by repeated analyses of sub-samples of the standards. The micronutrient concentrations in soils and vegetables were expressed in $mg\ .kg^{-1}$. The metal transfer factors were calculated as the concentration of the metal in the plant to the ratio of its concentration in the soil.

3.4 Data Analysis

The data were analysed using the SPSS software (SPSS Inc., Version 16.0). Analysis of variance was used to determine significant differences in the means between treatments. Means were separated by Duncan's Multiple Range Test (DMRT) at 5% significance level.

3.5 Economic Analysis

The results of the experiment were subjected to economic evaluation in order to test the economic viability of the different soil treatments used for radish cultivation [11]. The Average yield, average costs and average prices were used in the economic evaluation. Net profit (NP), marginal net return (MNR), revenue -to- cost ratio (RCR), and marginal rate of return or profit rate (MRR or PR) were calculated for different soil treatments. For RCR >1, profit is expected, but if RCR <1, no profit is expected. However, under the humid tropics, a RCR≥2 implies that a 100% MRR of the total investment is expected and that the application method or fertilizer type can be popularized. The gross benefit (GB) of a fertilizer treatment is obtained by multiplying the yield per treatment by the field price per kg of radishes. The operation cost (OC) on the other hand is comprised of the fertilizer cost (FC), transport cost (TC), fertilizer spreading cost (FSC), marginal net return (MNR) and the investment interest (II) during the planting period. The MNR is obtained by multiplication of the unit price of the radishes and the difference between the yield with fertilizer use and yield without fertilizer use. The MNR is obtained as the difference between the GR (gross revenue) and the RCF (revenue cost of fertilizers). The MRR (or PR) was calculated using the following expression:

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$$PR\left(or\ MRR\right)=\frac{MNR-RCF}{RCF}\times 100$$

4. Results

4.1 Petrography

The two main rock types studied are basalts and tephra. The basalt from Bamougoum occurs as lava flows and vertical prismatic columns which are either tetragonal or hexagonal in shape. The tephra outcrops are composed of clay-sized particles to decimetre-sized blocks of basaltic lavas.

Under the microscope, the rock is composed of olivine phenocrysts (25%), plagioclase (60%) and opaque minerals (15%). The texture is porphyritic (Figure A1). The main chemical constituents are silicon (45.36-46.42% SiO_2), aluminium (15.66-17.08% Al_2O_3) and iron (12.08-12.92% Fe_2O_3). Basic cations are also well represented, with calcium (8.43-9.40% CaO) as the most abundant element, followed by magnesium (4.58-6.68%MgO), sodium (3.69-3.86% Na_2O) and potassium (1.65-1.70% K_2O) (Table 1). Based on its silica content, the rock is classified as a basic rock. The trace elements in the rocks appear in two groups based on their concentrations; elements whose average concentrations in the rock are above 100 mg kg^{-1} (Ba, Cr, Ni, Sr, V and Zn and those whose mean concentrations are below 100 mg kg^{-1} (.Co, Rb, Be, Ga, Nb, Sc, Th and Y) (Table 1). The trace element composition compositions of the basalt and tephra are quite similar. The CIPW norms reveal that both basalt and tephra are olivine and diopside normative and quartz free (Table 1). For the REE concentrations of basalt and tephra, the light REE are far more abundant (ΣLREE: 247.7-317.28 ppm) compared to the heavy REE (ΣHREE: 12.07 to 13.65 ppm), giving a LREE/HREE ratio of 19.88 to 25.33. La is the most concentrated REE followed by Ce and Nd, while Lu is the least concentrated in the rocks.

Table 1. Major and trace elements and CIPW weight norm (%) composition (%) of basalts and tephra from Bamougoum Sub-division

Rock samples / Composition	Basalt 1	Basalt 2	Tephra 1	Tephra 2
Major elements (%Oxide)				
SiO_2	45.92	45.56	42.40	45.76
Al_2O_3	17.42.	13.91	14.51	14.81
Fe_2O_3	12.10	13.28	13.58	13.41
MgO	3.47	8.14	8.50	7.78
CaO	9.10	10.05	10.14	9.71
Na_2O	4.33	2.97	3.22	3.69
TiO_2	2.88	2.70	3.08	2.97
K_2O	1.77	1.01	1.22	1.45
P_2O_3	1.23	0.64	0.64	0.68
MnO	0.22	0.17	0.19	0.19
LOI	1.14	0.76	1.40	0.38
Total	99.62	98.82	98.98	100.15
Trace elements (mg kg^{-1})				
Ba	759	594	776	491
Co	48.8	44.7	39.9	47.7
Cr	466	201	207	340
Cu	42.8	53.9	36	45.8
Ni	109	124	90.5	179
Sr	949	965	1142	744
V	258	246	224	237
Rb	44.8	38.8	42.3	35
Be	1.13	1.22	1.63	1.2
Ga	19.5	20.1	21.5	20.5
Nb	95	77.9	96.4	64.5
Sc	22.3	19.6	18.6	19.3
Th	8.42	5.28	8.92	4.96
Y	28.9	25.9	28.10	24.3
Zn	119	112	130	131
Zr	286	234	276	213
Rare earth elements (mg kg^{-1})				
La	76.13	58.04	76.65	64.03
Ce	141.5	109.1	142.30	121.40
Pr	15.3	12.33	15.74	13.22
Nd	59.08	48.45	60.65	51.72
Sm	10.70	9.07	10.31	9.61
Eu	3.51	3.03	3.28	3.52
Gd	8.87	7.88	8.35	7.93
Tb	1.17	1.09	1.17	1.13
Dy	6.01	5.17	5.73	6.14
Ho	1.13	1.04	1.12	1.08
Er	2.55	2.31	2.59	2.47
Tm	0.35	0.29	0.35	0.34
Yb	2.09	1.88	2.07	2.18
Lu	0.31	0.29	0.24	0.31
ΣREE	328.7	259.97	330.55	285.08
LREE	315.09	247.9	317.28	271.43
HREE	12.44	12.07	13.27	13.65
LREE/HREE	25.33	20.54	23.91	19.88
Norm composition (%)				
Apatite	2.75	1.43	1.45	1.50
Ilmenite	5.54	5.22	5.22	5.67
Magnetite	2.73	2.99	2.99	2.98
Orthoclase	10.64	6.08	6.08	8.56
Albite	24.68	21.71	21.71	17.77
Anorthite	23.24	21.91	21.97	19.61
Diopside	12.09	19.95	19.95	19.78
Olivine	16.41	17.46	17.46	16.32
Nepheline	3.82	2.08	2.08	7.33
Total	98.90	98.87	98.66	99.53

4.2 Soil Characteristics

Physically, the studied soils are dark brown (10YR3/3) at the surface to reddish brown (7.5YR5/8) at depth and clayey in texture. Other soil properties are presented in Table 2.

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The soils of the experimental units, after treatment, show a slightly acidic pH, low exchangeable Ca, medium exchangeable Mg, low exchangeable K, low exchangeable Na, low sum of exchangeable bases, medium CEC, low available phosphorus (Table 3A). The base saturation is low and, apart from Ca/Mg ratio, all the other nutrient ratios are unbalanced (Table 3A). The soil pH globally increases from slightly acidic to alkaline following the different treatments. However, for all treatments, only T_4 shows a significant difference in pH compared to T_o after harvest (AH). The exchangeable Ca of T_3 is less concentrated in the treated soils after sowing (BS) as compared to the control (T_o) and varies from 0.35 (T_3) to 9.74 $cmol_c kg^{-1}$ (T_4) (Table 3A). After harvest, the exchangeable Ca ranges from 9.74 (T_3) to 11.18 $cmol_c kg^{-1}$(T_1). Apart from T_3, there is no significant difference in exchangeable Ca disparity among the different treatments. The Exchangeable Mg ranges from 1.91 to 2.98 $cmol_c kg^{-1}$, showing no significant difference among BS treatments and control. The Mg values of AH range from 2.24 (T_2) to 29.83 (T_1), and only T_1 fall below the control. The exchangeable K ranges from 0.68 to 2.66 $cmol_c kg^{-1}$, and all treatments of BS were significantly different ($P<0.05$) from the control (T_0). Exchangeable K of AH ranges from 0.1 to 1.36 $cmol_c kg^{-1}$, with a significant ($P<0.05$) decrease for T_3. The exchangeable Na is low for BS and AH, and there is no significant difference ($P<0.05$) between treatments. The sum of bases of BS ranges from 6.17 (T_3) to 13.15 $cmol_c kg^{-1}$ (T_4). The sum of bases of AH ranged from 12.42 (T_3) to 42.47 $cmol_c kg^{-1}$ (T_1). The available phosphorus varies from 1.02 to 14.06 ppm for BS and 7.22 to 69.43 ppm for AH. Apart from T_2, available phosphorus is relatively for all AH treatments compared to BS. The CEC varies between 13.76 $cmol_c kg^{-1}$ (T_1) and 18.30 $cmol_c kg^{-1}$ (T_4) at the start of the treatment, between 16.09 (T_2) and 18.30 $cmol_c kg^{-1}$

Table 2. Physical properties and micronutrient composition of a composite soil sample from the studied plot in Bamougoum

Physical properties / Horizon (cm)	Munsell colour (code)	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Porosity (%)	Particle size distribution (%)				Micronutrient concentration (mg kg^{-1})					
					sand	silt	clay	Textural class	Fe	Mn	Zn	Cu	Al	Fe/Mn
A1 (0-20)	dark brown (10YR3/3)	1.5	2.5	40	25	30	45	Clay	119.2	62.2	21.0	05.2	0	1.92
B1 (20-100)	reddish brown (7.5YR5/8)	1.6	2.6	38.5	19	25	54	Clay	-	-	-	-	-	-

Notes: Permissible limits for agricultural soils in mg kg^{-1} (Pesquini, 2006): Fe (50-250); Mn (15-500); Zn (150-300); Cu (50-140); Critical limits for normal plant growth in mg kg^{-1} [38]: Fe (<50); Mn (<20); Zn (150-300); Cu (50-140); Fe/Mg ratio [38]: Fe/Mn>2.5 (Fe toxicity); Fe/Mn<1.5 (Mn toxicity); 1.5<Fe/Mn<2.5 (Normal ratio for plant availability)

Table 3. Soil physico-chemical properties (A) and nutrient ratios (B) after treatment (BS) and after harvest of *R. sativus*.

(A)

Treatment	pH		Ca		Mg		K		Na		Sum of bases		CEC		Available P	
	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH
T_0	6.17		1.74		2.32		0.16		0.19		4.41		17.76		5.72	
T_1	6.07	6.49	8.92	11.18	2.57	29.83	0.89	0.95	0.28	0.51	12.54	42.47	16.58	16.68	1.02	29.79
T_2	6.14	6.39	7.86	9.45	1.91	2.24	0.68	1.36	0.16	0.26	10.61	13.31	13.76	16.09	14.06	14.24
T_3	6.01	6.5	0.35	9.74	2.98	2.46	2.66	0.10	0.17	0.12	6.17	12.42	17.47	16.70	4.83	69.43
T_4	6.14	8.56	9.74	10.35	2.22	2.44	1.03	1.01	0.16	0.22	13.15	14.02	18.30	18.95	2.60	7.22

(B)

Treatment	S/T ratio		Ca/Mg		Mg/K		Na/T (%)		Ca/Mg/K		CRC	
	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH	BS	AH
T_0	24.83		0.75		14.5		1.06		41.23/54.94*/3.83		3.05	
T_1	75.63	255	3.47	0.37	2.88	31.40	1.68	3.06	72.05/20.76/7.19*	26.64/71.09*/2.26	1.20	3.94
T_2	77.10	82.67	4.12	13.89	2.81	1.65	0.16	1.62	75.21/18.28/6.51*	72.41/17.16/10.43*	1.09	1.74
T_3	35.31	74.61	0.12	3.95	1.12	24.60	0.97	0.69	5.84/49.75/44.41*	79.19/20.3*/0.51	7.40	1.13
T_4	71.86	73.98	4.38	2.24	2.15	2.41	0.87	1.16	74.98/17.09/7.93*	75.22/17.68/7.10*	1.32	1.20

Notes: BS = soil sample after treatment; AH = Soil sample after harvest; T_0 = Control beds; T_1 = Basalt treatments; T_2 = Tephra treatments; T_3 = Effective microorganism (E.M.) treatments; T_4 = NPK fertilizer 20-10-10). Each value is a mean of 3 replicates. The critical values of the soil nutrients are summarized in Tabi et al. (2013). S/T = Base saturation; * = Most concentrated element that determines the direction of equilibrium; CRC = coefficient of relative concentration.

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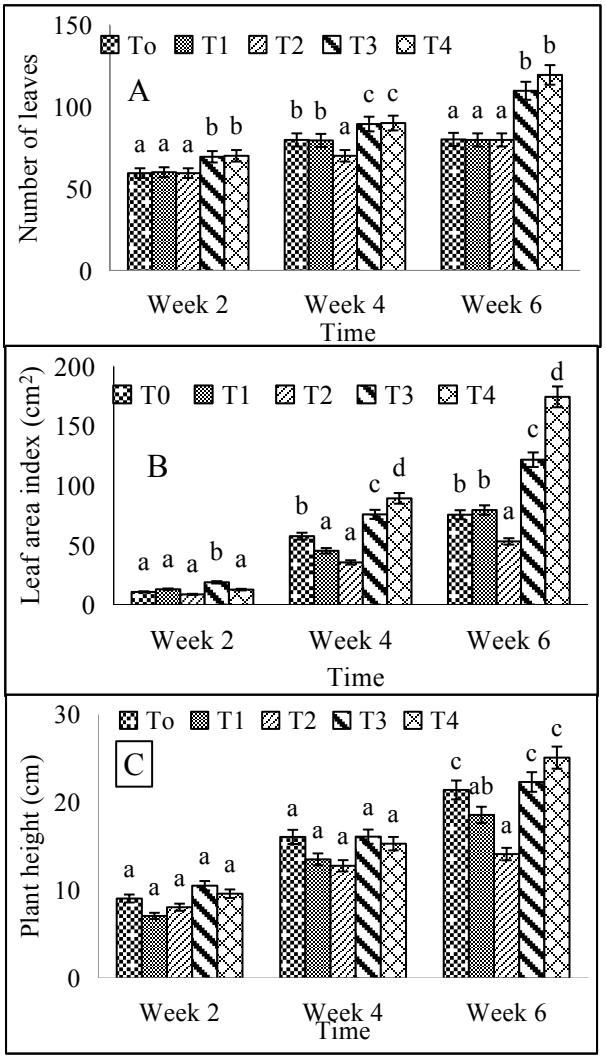
(T_4) at the end.

The soil nutrient ratios are compiled in Table 3B. The S/T ratios of BS soils vary from 24.83 (T_0) to 77.10% (T_2) while values of the AH soils range from 73.98% (T_3) to 255% (T_1). The Ca/Mg ratios indicate normal to optimum cation balance for BS, AH and the control, except for T_1 of BS and T_3 of AH with a cationic imbalance. The Mg/K ratios indicate a cationic imbalance for T_0 for those cations. Most of the treatments show a normal to optimum equilibrium, except for T_1 of BS and T_2 of AH that show low cation imbalance, as well as T_1 and T_3 of AH beds with a very strong cationic balance. The exchangeable sodium percentage (%Na/T) is very low (<5%) for all BS, AH and T_0. The Ca/Mg/K ratios indicate a cationic imbalance for T_0. Most of the BS beds are close to the optimum ideal condition (76% Ca, 18% Mg and 6% K) required for best plant absorption. Also, T_1 of AH, T_3 of BS and T_o show a cationic imbalance.



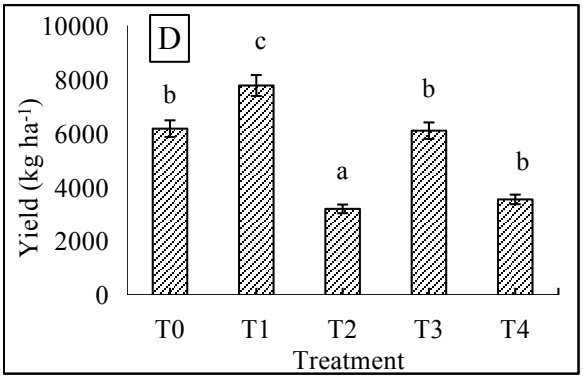


Figure 2. Weekly variation of number of leaves (A), leaf area index (B) and height (C) of *R. sativus* with time for different soil treatments and mean yield (D) per treatments (n = 10)

4.3 Growth and Yield Parameters

The Number of leaves increase gradually with time for all the soil treatments (Figure 2A). The number of leaves in week 2 reveals a significant difference (P<0.05) with those of the other weeks; the highest number of leaves is observed for T_4 (70.30 ± 0.15) and the lowest for T_2 (59.70± 0.12). Among the treatments, the number of leaves are significantly different (P<0.05) in week 4. The highest number of leaves are recorded for T_4 (90.3±0.35) and the least for T_2 (70.30 ± 0.55). There is also a significant difference in the number of leaves in week 6 (P<0.05). Meanwhile, T_4 (119.70±0.15) is significantly high and T_0 (80.30 ± 0.75), T_1 (80.00 ± 0.26) and T_2 (80.00 ± 0.17) show the lowest values.

The LAI increases progressively with time (Figure 2B). Among the treatments, the LAI is not significantly different (P<0.05) in weeks 2 and 4. The highest LAI is noted in T_4 (89.42 ± 6.64 cm^2) and the lowest one for T_2 (35.73 ± 4.84 cm^2). A similar trend is observed after week 6, where the highest LAI value is 174.54 ± 18.46 cm^2 (T_4) and the lowest one is 53.35 ± 5.49 cm^2 (T_2).

The plant height increases gradually with time for all treatments (Figure 2C). After week 2, a significant difference (P <0.05) is observed in plant height for all the treatments and the control. The highest plant height is recorded for T_3 (10.55 cm ± 1.43) and the lowest one for T_1 (7.11 ± 1.20 cm). A significant difference (P <0.05) in plant height after week 4 is marked by T_3 having tallest plants (16.12 ±1.19 cm) and T_2 (12.81 ± 2.12 cm) as shortest ones. After week 6, maximum height is recorded for T_4 (25.10 cm ± 1.46) and the lowest one for T_2 (14.14 ± 0.81 cm).

The mean yield of Radish ranges from 3200.52 ± 39.47

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kg ha^{-1} to 7775.36 ± 16.52 kg ha^{-1}. The yields increase as follows: T_1>T_0>T_3>T4>T_2 (Figure. 2D). There is a significant difference (P <0.05) in the yield (kg ha^{-1}) between T_2 and T_4 and the rest of the treatments and the control.

4.4 Micronutrient Concentrations in Leaves and Bulbs of the Radish

The micronutrients levels of bulbs and leaves of Radish are shown in Table 4 and Figure 3A.

In bulbs, Fe contents vary from 12.2 to 129.9 mg kg^{-1}. The highest Fe contents occur in T_1 bulbs while the lowest occur in T_0 bulbs. Apart from Fe contents of T_0 and T_4 that show no significant difference, those of the rest of the treatments are significantly different (P<0.05). The transfer factors range from 0.12 to 2.09, with highest values noted for T_1 and T_2 bulbs (Figure 3B). The Mn contents of the bulbs vary from 11.2 to 29.04 mg kg^{-1}, with the highest levels noted in T_2 and the lowest ones in T_0. T_0 and T_1 bulbs do not show any significant difference in Mn levels, just like T_1 and T_2 bulbs. The transfer factors vary from 0.18 to 0.47, with highest values noted for T_1 and T_2. The Zn contents of the bulb fluctuate between 0.43 and 1.92 mg kg^{-1} with T_2 showing the highest levels and T_4 is shows the lowest ones. Treatments T_0, T_3 and T_4 show no significant difference among themselves just like T_1 and T_2. The transfer factors of Zn vary from 0.02 to 0.9, with highest values noted for T_1 and T_2 (Figure 3B). The concentrations of Cu in the bulbs are almost similar to those of Zn (0.20 to 1.80 mg kg^{-1}), with treatments T_2 and T_1 showing the highest accumulations of the metal in the plant tissue while T_3 shows the least. Just as for Zn, treatments T_0, T_3 and T_4 show no significant difference in Cu concentrations among themselves just like T_1 and T_2. The transfer factors vary from 0.04 to 35, with highest values observed for T_1 and T_2 bulbs.

The Zn contents vary from 0.21 to 2.1 mg kg^{-1} and the highest concentrations appear in T_1 and T_2 plant bulbs while the lowest ones are observed in T_4 bulbs. There is no significant difference (P<0.05) between Fe contents of the T_1 and T_2 bulbs as well as bulbs of T_0, T_3 and T_4. However, Fe contents of T_1 and T_2 plant bulbs are significantly different from those of T_0, T_3 and T_4.

The microelements concentrations of the leaves are globally lower than those of the bulbs, except for Cu content of T_4 plants (Table 4). The concentrations of Fe in the Radish leaves vary from 2.2 to 18.6 mg kg^{-1}. The highest accumulations were observed in the T_1 and T_2 plants, with comparable levels without any significant difference. The Fe contents in leaves of the rest of the treatments are significantly lower than those of T_1 and T_2 but show no significant differences among themselves. The transfer factors of Fe from soil to leaves vary from 0.02 to 1.6, with highest values observed for T_1 and T_2 plants (Figure 3B). The Mn contents of the leaves vary from 1.99 to 9.2 mg kg^{-1}. The highest accumulations occur in T_2 plants followed by T_3 plants. The lowest concentrations are observed in T_4 plants followed by T_1 plants. The Mn contents of T_1 and T_4 plants show no significant difference (P<0.05), just like the concentrations of T_2 and T_3 plant leaves. The transfer factors of Mn from soil to leaves vary from 0.03 to 0.15, with highest values observed for T_2 followed by T_3, and T_1 plants attain a transfer factor of only 0.08. The lowest values are shown by T_0 and T_4 plants (Fig. 3B). The Zn concentrations in the Radish leaves vary from 0.21

Table 4. Micronutrient composition of leaves and bulbs of the mature Beetroot per treatments (n=10)

Treatment \ Micronutrient	Fe		Mn		Zn		Cu	
	bulb	leaves	bulb	leaves	Bulb	leaves	bulb	leaves
Micronutrient concentration (mg kg^{-1})								
T_0	12.2^a	2.9^b	11.2^a	2.2^a	0.37^a	0.84^a	0.52^a	0.22a
T_1	129.9^d	16.7^d	26.99^c	4.8^b	1.57^b	2.10^b	1.32^b	0.62a
T_2	71.8^c	18.6^c	29.04^c	9.2^c	1.92^b	1.34^b	1.80^b	1.03a
T_3	30.2^b	2.4^a	19.88^{ab}	6.3^b	0.63^a	0.42^a	0.20^a	0.19a
T_4	14.01^a	2.2^a	15.20^a	1.99^a	0.33^a	0.21^a	0.23^a	0.26a
Micronutrient transfer factors from soil to organ								
T_0	0.10^a	0.02^a	0.18^a	0.04^a	0.02^a	0.04a	0.10^a	0.04^a
T_1	1.09^c	0.14^b	0.43^{ab}	0.08^b	0.07^b	0.10b	0.25^b	0.12^b
T_2	0.60^b	0.16^b	0.47^{ab}	0.15^b	0.09^b	0.06b	0.35^b	0.20^c
T_3	0.25^a	0.02^a	0.32^a	0.10^b	0.03^a	0.02a	0.04^a	0.04^a
T_4	0.12^a	0.02^a	0.24^a	0.03^a	0.02^a	0.01a	0.04^a	0.05^a
Predefined standards of micronutrients								
Normal levels in plants [23]	50- 500		5-20		20-1000		1-400	
Critical levels for plant growth [23]	50-150		20-100		300-500		100-400	
Toxicity levels in plants [13]	>500		20-30		>500		>400	
Sufficiency levels in food [17]	-		<200		-		<500	

Note: Means in the same column followed by the same letters are not significantly different (P < 0.05).

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to 2.10 mg kg^{-1}. The highest levels of Zn are observed in T_1 and T_2 plants and lowest occur in T_3 and T_4 plants. The Zn levels of T_1 and T_2 plants are not significantly different ($P<0.05$) but significantly different from T_0, T_3 and T_4 plants which are also not significantly different among themselves. The transfer factors of Zn from soil to leaves range from 0.01 to 0.10, with highest values observed for T_1 and T_2. The Cu concentrations of the Radish leaves fluctuate between 0.22 and 1.03. The highest concentrations appear in T_2 and T_1 plants while the lowest ones are noted in T_3. The Cu contents of T_1 and T_2 are not significantly different from one another, but significantly different from the metal concentrations in the other treatments. The transfer factors of Cu from soil to leaves fluctuate from 0.04 to 0.20, with highest values in T_1 and T_2 leaves (Figure 3B).

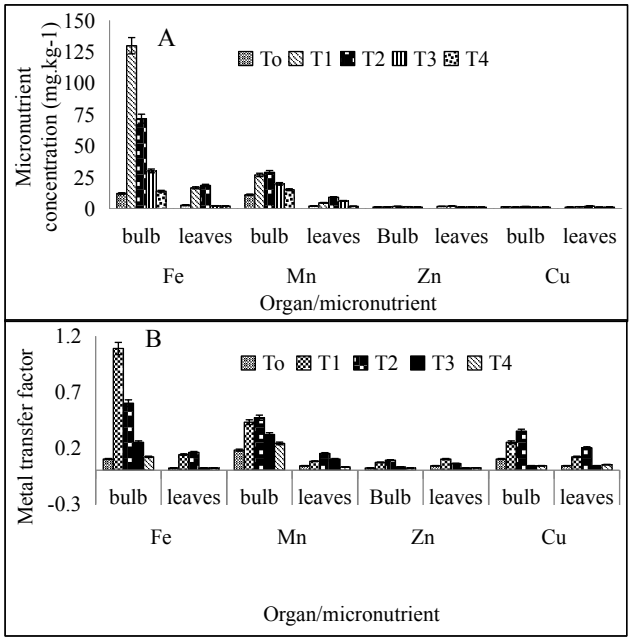

Figure 3. Micronutrient composition of bulbs and leaves (A) and soil-to-organ metal transfer factors (B) in Radish for different treatments after harvest (n=10)

4.5 Economic Analysis of the Treatments

Treatments T_3 and T_4 are very expensive relative to T_1 and T_2 (Table 5). Also, for all treatments, the total expenditure is far below the total gross return (GR) implying a positive balance sheet for all the soil treatments. However, T_1 gives the highest GR, with a substantial supplementary profit rate of 333% following the application of basalt dusts (Table 5). Compared to T_0, there is a drop in GR for the rest of the treatments. A profit reduction is thus observed as a result of those treatments as revealed by the negative yield due to treatment and marginal net return (MNR). Thus, apart from T_1, the other treatments are less profitable compared to T_0.

5. Discussion

5.1 Influence of Different Treatments on Soil Properties

In all the treatments, a slight rise in pH from slightly acidic to slightly alkaline is observed. This pH interval is best for the cultivation of radish and indicates that the different treatments amended the soil fertility by reducing its acidity [33]. This pH increment has a positive impact on other chemical properties, base saturation, cationic balance and microbial activity [14]. The fact that exchangeable bases increase after harvest for all treatments (except T_3) could imply that more basic cations have been released into the soil during plant growth as confirmed by an increase in base saturation of those treatments. Basalt and tephra dusts remineralise the soil by adding trace elements that were initially low in T_0. The fineness of the basalt dust enhanced rapid weathering and the release of nutrients into the soil. Treatment T_1 reveals the highest transfer of exchangeable bases (Ca^{2+}, Mg^{2+} and K^{+}) from rock powder to the soil, probably portraying a high fertilizing potential of the basalt dust [14]. This might justify why radishes from T_1 show

Table 5. Economic analysis of the different soil treatments for radish cultivation (n = 10)

Treatment	AY (Kg/ha)	EY (Kg/ha)	GR (FCFA)	FC (FCFA)	TEEY (FCFA)	FSC CFA)	FTC (FCFA)	OC (FCFA)	II	RCF (FCFA)	MNR (FCFA)	RCR	NR (FCFA)	PR (%)
T_0	6175.36	0	9,880,576	0	0	0	0	0	0	0	0	0	0	0
T_1	7775.36	1600.2	12,440,576	35000	6000	30000	2000	74600.2	1865.00	76465.15	2560.32	3.34	2483854.85	333
T_2	3200.52	-2974.6	5,120,832	35000	6000	30000	2000	70025.4	1750.63	71776	- 4, 759.36	-66.3	-4831136.00	-67.31
T_3	6100.85	-74.3	9,761,360	216000	5500	30000	2000	253425.7	6335.6	259761.3	-118.88	-0.46	-378641.30	-1.46
T_4	3550.74	-2624.4	5,680864	490000	5500	30000	2000	524875.6	13121.89	537997.5	-4199.04	-7.80	-4737037.50	-8.80

Notes: AY: Average yield; GR: Gross return; EY: Extra yield (due to fertilizer use); FC: Fertilizer cost; TEEY: Total expenditure on extra yield; FSC: Fertilizer spreading cost; FTC: Fertilizer transport cost; OC: Total cost; II: Interest on investment (4.25% per annum in Cameroon); RCF: Revenue cost of fertilizers; MNR: Marginal net return; RCR: Revenue-to-cost ratio; NR: net return; PR (%): Profit rate (due to soil treatment); FCFA: Francs French Currency in Africa; 1US $ 1 ≈ 600 FCFA (May 2016); Cost of radish in the market ≈ 1600 FCFA/kg. Each value is a mean of 3 replicates

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the best yields; in T_1 soils, base saturation is high and the absorption complex is saturated with exchangeable bases (Ca and Mg). The available phosphorus content of the soils after harvest (AH) is such that $T_3>T_1>T_2>T_4$. Hence, high phosphorus content in treatment T_3 could be linked to rapid organic matter mineralisation by biological activity from the inoculant microorganisms [33,34]. Available phosphorus is a booster of mineral nutrient uptake and an essential element to plant organs at early growing stage [21,24]. This could explain why T_3 plants show no morphological significant difference to T_4 plants. The Mg/K ratio shows a normal to optimum level of Mg and K for all the treatments [26]. The Ca/Mg ratio reveals a cationic balance between exchangeable magnesium and calcium for all the treatments [25]. The Ca/Mg/K ratio indicates a cationic imbalance for the three bases for To, T_3 plants of BS, and T_1 plants of AH compared to the ideal equilibrium state of 76% Ca, 18% Mg and 6% K values necessary for optimum plant nutrient uptake by plants [27]. This suggests that although the cations were present in sufficient amount necessary for good crop performance in these soils, their uptake might have somehow been limited due to cationic imbalance [31].

5.2 Implications of Different Treatments on *R. sativus* Performance

In this study, the growth parameters of *R. sativus* increase gradually from the second week through the sixth week where the plant attains maturity. Mean values of plant height and leaf area index are as follows: $T_4>T_3>T_0>T_1>T_2$. T_3 and T_4 show the highest number of leaves, leaf area index and plant height certainly due to the high nitrogen and phosphorus supplied by NPK which favoured plant growth through formation of tissues. Josh and Petil [7] and Dixon [19] proved nitrogen fertilizers to be essential components of the chlorophyll molecule and protein synthesis. The outstanding performance of T_3 leaf count, LAI and plant height could be attributed to mechanisms like soil structural modification, changes in available water content, increased availability of macro- and micronutrients, stimulation of microbial activities and increase in critical enzyme activities necessary for tissue synthesis [39]. The fresh yields of the radish bulbs follow this trend: $T_1>T_0>T_3>T_4>T_2$. The highest yield obtained from treatment T_1 could be attributed to a number of factors as already documented: Gillman [14] observed that basalt dust slowly increases soil pH just as lime, although over a longer period of time, but generates less stress on plant growth. Moreover, basalt dust forms a symbiotic relationship with the microbial activity in soil which is crucial in clay-humus complex formation. Also, the fine particle size of this basalt might have hastened the dissolution of essential minerals needed for plants growth [5]. In this study, basalt dust shows a better performance than tephra despite their similar chemical and mineralogical compositions. Basalt dust, unlike other rocks, is paramagnetic and some samples are more paramagnetic than others [5]. One theory holds that this energy is ferromagnetic and is emitted by magnetite within rocks originating from deep within the mantle. This ferromagnetism is beneficial to plant growth as it encourages strong growth of soil microbes, fungi and plant roots, thereby increasing crop yield [15]. Possible differences in paramagnetism between basalt and tephra might explain the differences in performance of the two rock powders recorded in radish growth and yield,. Works of [9] showed that basalt dust with the highest magnetic intensity exhibits the best radish performance. Callahan [5] showed the disparity in performance between two quarry materials; one was hydrated basalt having flown into freshwater and its nutrients were more available to plants than basalt that cooled on land. The increased weathering of minerals in the rhizosphere has the tendency to induce changes in the abundance and the forms of metals at soil-root interface [39]. Although T_3 and T_4 plants record the most expressed morphological parameters, they however show lower yields compared to T_1, T_0 and T_2. Potential sources of reduction of fertilizer efficiency and hence yield reduction are poor land preparation (10-25%), inappropriate crop variety (20-40%), poor timing (20-40%), improper seeding (5-20%), poor planting density (10-25%), poor irrigation (10-20%), weed infestation (15-50%), insect attack (5-50%), imbalanced fertilizer application (20-50%), improper fertilizer application (5-10%) [3]. For T_1, although exchangeable cations (Mg^{2+}, Ca^{2+} and K^{+}) were released into the soil, yields remained low probably because the quantity was not enough to meet the plant needs [31] or due to cation imbalance that impeded nutrient uptake [30]. The plant needs K for photosynthesis, carbohydrate translocation, water regulation, protein synthesis and proper root development while calcium plays a role in proper root development [39]. Some authors [29,34] reported the important role played by silicon in protecting crops against diseases and micronutrient toxicities; it improves root growth, plant structural strength as well as soil properties like soil aggregation and water holding capacity. Rock dust has been described as more "intelligent" than most chemical fertilizers as their positive effects increase with time of application [14]. In the present work, time of rock dust application was short and it is possible that yields could increase in subsequent planting seasons

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due to residual effect of the weathered rock. This agrees with [32,36] whose rock dust trials on plants show significant effects five times stronger than untreated controls a few years after application. The effects of rock dust on plant growth and subsequent soil remineralisation are of importance in biologically orientated agriculture [21]; this enabled recent developments in the use of rock dust as fertilisers to be described as "Stone Age" farming [5]. Complex ferromagnesian silicates (olivine, pyroxene and amphiboles, etc) in basalt release Ca, Mg, K, P and micronutrients on weathering which are essential for plant growth [16]. It is thus a recommended additive to leached soils. The use of rock dust also seems environmentally friendly than chemical fertilizers [36]. The nutrients released by rock dust are directly related to weathering rate, thus, their beneficial effect may last for many years before needing replacement, if combined with sustainable farming techniques [20].

5.3 Micronutrients Concentrations in the Soil, Leaves and Bulbs

In T_o, the micronutrients Fe and Mn are within the permissible limits for agricultural soils meanwhile Zn and Cu are below these limits [20]. Fe and Mn are above the critical limits for normal plant growth while Zn and Cu are below these limits [20]. These results agree with those of [3] for some arable soils in the Cameroon Western Highlands. In effect, micronutrients tend to be available in soils under strongly acidic conditions but become less available as pH gets closer to neutrality [21].

The Fe contents in the bulbs vary from 12.2 to 129.9 mg kg^{-1}: concentrations of T_1 and T_2 plant bulbs fall within the normal levels in plants and above the critical levels for plant growth, while the Fe contents of bulbs from the rest of the treatments are below these standards [23]. In the leaves, the Fe contents of all the treatments fall below normal levels in plants and below the critical levels for plant growth [23]. The Fe contents of bulbs and leaves fall below toxicity levels in plants [13].

Mn concentrations of bulbs and leaves are below the sufficiency levels in food [17]. In the bulbs, Mn levels of the T_1 and T_2 bulbs are above normal levels in plants and above the critical range for plants as well as above the toxicity level in plants [13]. In leaves, except for T_2 and T_3, Mn levels are below normal levels in plants and below critical levels for plant growth as well as below toxicity levels in plants [13].

The Zn concentrations of the bulb and leaves of the Radish fluctuate between 0.43 and 1.92 mg kg^{-1} and 0.21 to 2.10 mg kg^{-1}. These ranges are below normal levels in plants and below the critical levels for plant growth [23] as well as below the toxicity levels in plants [13].

The concentrations of Cu in the bulbs are 0.20 to 1.80 mg kg^{-1} while those in the leaves are 0.19 to 1.03 mg kg^{-1}. The Cu contents of T_1 and T_2 in bulbs and T_2 in leaves fall within the normal levels in plants while the rest of the treatments gave leaves and bulbs with Cu levels below this standards [23]. All the Cu concentrations in leaves and bulbs are below critical levels for plant growth [13] and below toxicity levels in plants and below sufficiency levels in food [17].

The application of rock dusts enables to improve the micronutrients levels in the radish leaves and bulbs. This is further confirmed by the transfer factors of micronutrients of T_1 and T_2 leaves and bulbs which are significantly higher than in leaves and bulbs of T_0, T_3 and T_4 plants. The plant tissues present micronutrient concentrations which will not pose any danger of heavy metal toxicity to humans. The radish plants might therefore serve as nutrient supplement especially for children and expectant mothers.

5.4 Economic Outcomes of the Different Treatments

The most economically viable soil treatment in terms of yield is attained by T_1 with a profit rate (PR) of 333% and a RCR value of 3.34. According to [12], a RCR value greater than 2 implies that at least 100% of the investments will be recovered from the yields. Basalt dust can thus be popularized for the cultivation of radish. Compared to T_0, there is a sharp drop in PR for the rest of the treatments as revealed by the negative extra yield (EY) obtained from fertilizer application and marginal net return (MNR) values. Similarly, [14] revealed that after applying basalt dust on radish at a rate of 10 tons ha^{-1} on clayey soils, a reduction in available phosphorus requirements by 70 kg ha^{-1}, equivalent to 38 US dollars ha^{-1}, was realized. Oldfield [29] used rock dusts at 10 tons ha^{-1} to substitute for the equivalence of 25% fertilizer requirements for the same yields; after applying 4 tons ha^{-1} of basaltic dust on radish, yields did not vary much but crops showed reduced diseases.

5. Conclusions

The present study was focused on the evaluation of the fertilizing potentials of basalt and tephra dusts on the growth and productivity of radish (*Raphanus sativus*) compared to organic manure and chemical fertilizers. The results show that the highest radish yields were recorded basalt (T_1), followed by control soil (T_o), effective micro-organisms manure (T_3), then NPK 20-10-10 (T_4) and lowest yields were shown by tephra dust (T_2). Instead, T_4 showed the highest number of leaves,

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LAI and plant height after six weeks. Soils treated with basalt dust showed the highest levels of exchangeable bases of BS soils. Also, after treatment with basalt and tephra dusts, the soils exhibited a more balanced cationic equilibrium compared to control making it easier for the plant to absorb nutrients from the soil. Although tephra treatment showed the least yield of radish, soil fertility parameters like pH, cation exchange capacity, sum of exchangeable bases, base saturation, available phosphorus and cation balance were improved after tephra dust addition. The most economically viable soil treatment in terms of yield was attained on soils treated with basalt dust (T_1) probably portraying a high fertilizing potential of this rock powder. The micronutrient (Fe, Mn, Cu and Zn) levels of leaves and bulbs were significantly higher in basalt and tephra treated plants compared to the plants fertilized with NPK 20 20 20, effective micro-organism manure. The micronutrient levels in bulbs and leaves will not pose any danger of heavy metal toxicity to humans and could thus be recommended as nutrient supplement, especially to children and expectant mothers. These results reveal that basalt dust could be popularized as an alternative to chemical fertilizers for radish cultivation.

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Conflict of Interest

The authors confirm that this article content has no conflict of interest

Appendixes

Table A1. Yield of *R. sativus* per treatment (n=10)

Treatment	Mean yield (g)	Yield ± SD (kg ha^{-1})	Relative yield (%)
T_0	124	6175.15± 62.41 ^{b}	23.04
T_1	156	7775.36± 16.52 ^{c}	29.01
T_2	64	3200.52± 39.47 ^{a}	11.94
T_3	122	6100.85± 54.48 ^{b}	22.76
T_4	71	3550.74± 48.96 ^{a}	13.25

Notes: Means in the same column followed by the same letters are not significantly different ($P < 0.05$). T_0 = Control beds; T_1 = Basalt treatments; T_2 = Tephra treatments; T_3 = Effective microorganism (E.M.) treatments; T_4 = NPK fertilizer 20-10-10); SD = Standard deviation. Each value is a mean of 3 replicates.

Table A2. Mean variation (± standard deviation) of leaf count, leaf area index and plant height (n=10 plants)

Treatment	Week 2	Week 4	Week 6
	Leaf count		
T_0	59.70 ± 0.32^a	80.00 ± 0.78^b	80.30 ± 0.75^a
T_1	60.30 ± 0.12^a	79.70 ± 0.55^b	80.00 ± 0.26^a
T_2	59.70 ± 0.12^a	70.30 ± 0.55^a	80.00 ± 0.17^a
T_3	69.70 ± 0.21^b	89.70 ± 0.32^c	110.00 ± 0.30^b
T_4	70.30 ± 0.15^b	90.30 ± 0.35^c	119.70 ± 0.15^b
	Leaf area index (cm^2)		
T_0	10.95 ± 2.75^a	57.73 ± 17.56^{ab}	75.71 ± 5.47^b
T_1	13.19 ± 4.94^a	45.47 ± 9.95^{ab}	79.61 ± 2.10^b
T_2	8.92 ± 0.40^a	35.73 ± 4.84^a	53.34 ± 5.49^a
T_3	19.03 ± 2.89^b	76.00 ± 17.63^{bc}	121.85 ± 5.96^c
T_4	12.92 ± 4.28^a	89.42 ± 6.64^c	174.54 ± 1.06^d
	Plant height (cm)		
T_0	9.09 ± 1.66^a	16.09 ± 1.56^a	21.43 ± 4.45^c
T_1	7.11 ± 1.20^a	13.54 ± 0.74^a	18.59 ± 1.13^{ab}
T_2	8.10 ± 1.31^a	12.81 ± 2.12^a	14.14 ± 0.81^a
T_3	10.55 ± 1.43^a	16.12 ± 1.19a	22.33 ± 1.66^c
T_4	9.64 ± 0.73^a	15.32 ± 2.43^a	25.10 ± 1.46^c

Note: Means in the same column with the same superscripts are not significantly different according ($P < 0.05$).

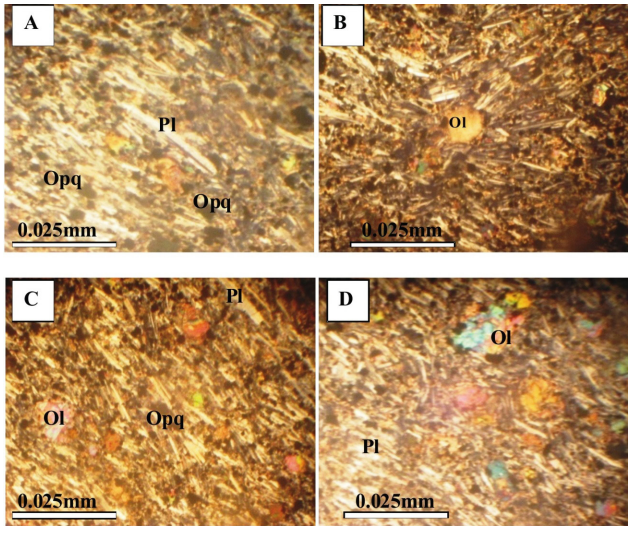

Figure A1. Photomicrographs (A-D) of basalt in Bamougoum. Pl = Plagioclase; Opq = Opaque mineral; Ol = Olivine

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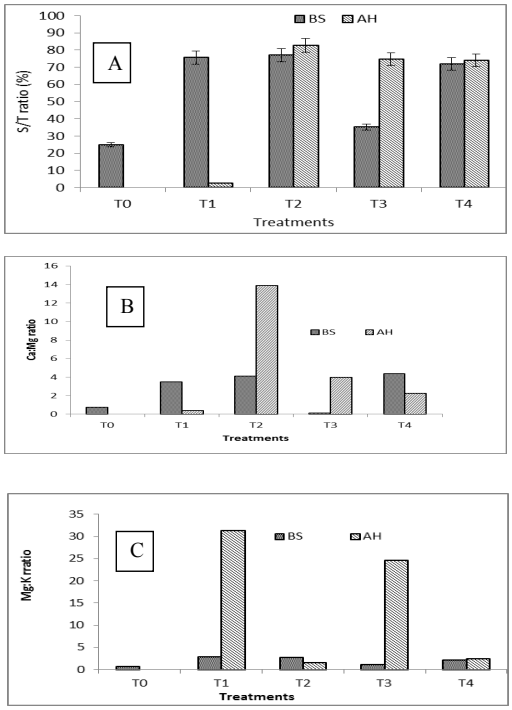
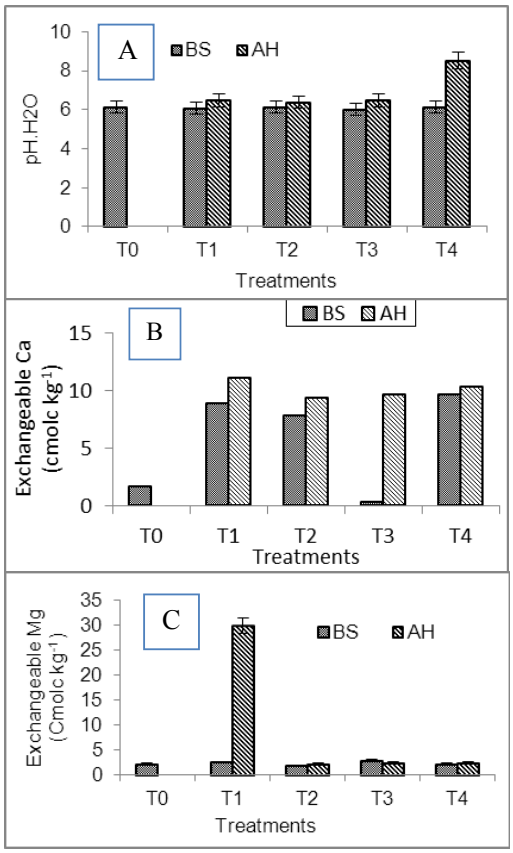


Figure A2. Nutrient ratios for the different treatments (n = 10). BS = Treated soil after treatment; AH = Treated soil after harvest; T_0 = Control bed; T_1 = Basalt treatments; T_2 = Tephra treatments; T_3 = Effective microorganism (E.M.) treatments; T_4 = NPK fertilizer 20-10-10)



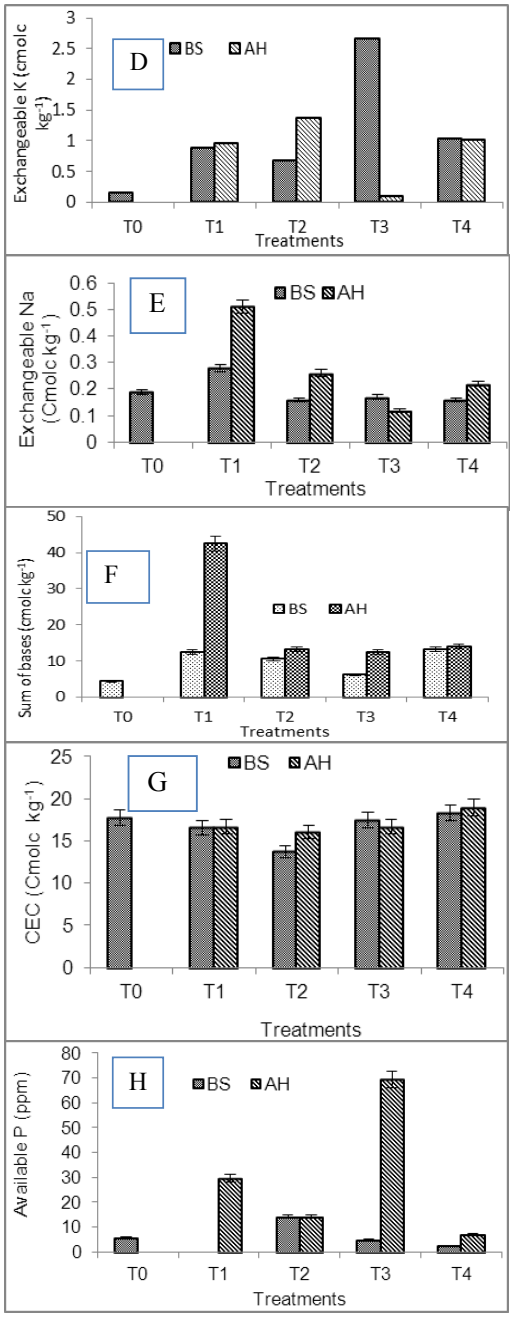


Figure A3. Mean (± standard deviation) variation of soil characteristics for different treatments. BS: Soil after treatment; AH: soil after harvest; T_0 = Control bed; T_1 = Basalt treatments; T_2 = Tephra treatments; T_3 = Effective microorganism (E.M.) treatments; T_4 = NPK fertilizer 20-10-10)

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REVIEW

A Comprehensive Review of Water Quality Monitoring and Assessment in Delta State, Southern Part of Nigeria

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ABSTRACT

This research presents a review on water resources in Delta state, southern part of Nigeria, with emphasis on hydrogeochemical and microbial assessment. It evaluates factors responsible for water contamination, and their resulting health challenges within the study area. To achieve the objective of this study, related articles were downloaded from Google, published article on influence of hydrogeochemical and microbial activities on water resources. These articles were thoroughly studied. Findings from this study, suggested that groundwater was more studied than surface water. We also observed that groundwater within the riverine communities is much more prone to pollution when compared to groundwater in an upland area. Results from various authors suggested that, larger percentage of groundwater showed presence of coliform. Further findings suggested that geochemical processes such as rock water interaction, seawater intrusion and precipitation influences groundwater quality within the study area especially within Sombreiro-Warri Deltaic Plain Deposit.

1. Introduction

Water resource is a vital natural resource, utilized by millions of people across the globe for drinking, irrigation, industrial, and other use. [1] were of the view that nearly 1.1 billion people are deprived access to potable water globally, and that human life is lost every year from water- related diseases. [2] reported that for water to be of good quality, it must be colourless, odourless, tasteless and free from faecal pollution. The quality of water depends on the physicochemical and biological attribute of the water, which in turns depends on the geology of the area and also impacts of anthropogenic activities [3]. Water may be available in large quantity but if it is contaminated is considered unfit for use. It is better for water resource to be small in quantity and free from contaminations. It would have been easier to mitigate water resource pollution if the state and federal government were to be in charge of water supply for domestic use, unlike in time past (before independence) in Nigeria, were the government was in charge of water supply and it was free for inhabitant of the study area. However, in today's world water supply is strictly left in the hands of individuals this has led to individual sitting personnel borehole in their premises for domestic water use. While people living around the riverine community/ creeks solely rely on surface water (stream and river) for do-

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mestic use. In most, cases individuals and governments emphasize more of water quantity rather than laying emphasis on its quality [4,5]. [6] stated that most part of the study area is richly blessed water resources, but the major concern is that the water resource of the area is highly prone to pollution/ contamination from various sources. [7] reported that globally most of the health related problems is linked to water borne disease as shown in Table 2. [8] further reported that wastewater from petroleum flow stations are continually being discharged indiscriminately into surface water resulting to impairment of water quality, especially in oil producing communities within the study area. [9,10,12,13,14,15] were of the view that pollution of water bodies was attributed to indiscriminate use fertilizers, rural-urban migration, exploration of crude oil, mismanagement of natural water resources and construction activities especially by construction companies. According to [16] there are other sources of water pollution aside oil spill, the occurrence of these oil spills and other anthropogenic activities has led to serious pollution of water resources within the study area. Some of the towns and village affected by oil spillage in study area include the following: Jesse, Opukebe, Jone Creek, Afisere, Uzere, Kwale, Ogulahga, Ozoro, Ekerejegbe, Olomoro, Ekakpare and Otorogu. [17] reported that oil exploration and exploitation in the Niger Delta especially within the creek have also undoubtedly, contributed decline in water quality. [18] further reported that groundwater pollution is on the increase across major town and cities where human activities have continuously prevailed. [18] were of the view that most sewage system construction by individuals usually lack environmental regulatory control and thus quality is compromised, thereby leading to collapse of most septic tanks which in-turn finds its way into surface and groundwater. They further reported that human wastes contain sodium (Na^+) and chloride (Cl^-) and they are often disposed in onsite septic systems and that consequently, elevated concentrations of Na^+ and Cl^- in groundwater. [19], assessed groundwater quality in residential areas close to dumpsites in Warri and environs. Their findings showed that the first aquifer in Warri from which most wells and boreholes are tapping water from, acidic water with low pH value which renders water unfit for drinking in the area except if it is treated. [20] studied groundwater in selected area across Delta state. It was the first paper to such report such holistic finding. Their results showed that the study area has low pH and low salinity. High iron content was discovered in water and there was occurrence of faecel in water. [21] reported that most of the water samples within Okwagbe in Delta state were acidic groundwater being the most acidic. [22] reported that Niger Delta is not essentially rich in nitrate. Moreover excess of nitrate in water may lead to water pollution as shown in Table 2. Previous studies have shown a significant decline of water resources in the study area [18,23,24,25,26,27,28]. Microorganisms are mostly found in surface water. In rare scenario they are found in groundwater when groundwater is directly polluted by surface water. [29], acknowledge that faecal contaminant such as *E. coli(s)* are considered to be high threat to water bodies more especially in un-planned urban were water supply is left in the hand of individuals. [30,31] were of the view that bacteriologically polluted water is considered to be highly dangerous to health because it can lead to possible outbreaks of typhoid, cholera epidemics. Different microorganisms can be found in water. [32] stated that in a practice sense it impossible to constantly check, differentiate the various kinds of disease-causing microorganism present in water. In most cases, microorganisms (colioforms) can be used to assess water for microbial contamination. [33,34] were of the opinion that coliform bacteria may not be pathogenic, but might predict the possibility, but not the certainty, of the presence of pathogenic microbes that can cause hazardous diseases. [35] further pointed out that pathogens are mostly spread by untreated or poorly treated sewage in water-borne infections. A lot of disease in this generation are related to contaminants ingested in into water bodies. According to [31] poor physicochemical quality of water may have adverse health effects causing avoidable economic and human losses. In the same vein, a detailed knowledge of geochemistry is considered paramount in evaluating the hydrochemistry of water and plan the monitoring of water quality [36,37]. [38] acknowledge that surface water on a global scale serves as recipient of great quantities of waste discharged through agriculture, industrial, domestic and petroleum related activities. This has led to pure and hygienic water scarcity, disruption of socioeconomic activities and poor aesthetic quality of most of the water bodies Although several scholar that evaluated water resources of the study area compared sampled results to water quality guidelines by [39]; [40] and it acceptability of public drinking water supplies. However, the study of [20] access groundwater quality in Delta state, Nigeria. Although the study is of upmost importance, as it extensively discusses groundwater quality in the aforementioned area, but the study was undertaken more than 12 years ago. It is of upmost importance to carry out this study and establish the current status of groundwater in Delta state. The present study reports the major results of research focused on effect of microbial, anthropogenic and geogenic activities on water resource quality in Delta state. Within the scope of the authors exhaustive search, there are no detailed reviews on the effect of anthropogenic/geogenic activities on water resources of Delta State context. Hence, this study was initiated to review the quality of water resources within the study area with emphasis on hydrogeochemistry and microbial studies. Furthermore, diverse recommendations are preferred in the paper which is considered necessary for future

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monitoring of water resources of the study area. Literature on generalized on studies on surface and groundwater of the Delta state, Nigeria (the Niger Delta Basin) is shown in Table 1 and also found elsewhere.

2. Study Area

2.1 Location, Climate and Vegetation

The study area lies in the western part of the Niger Delta region. It spans over 15,000 km^2 and it is among one of the leading states in oil production in Nigeria [20]. The study area, lies approximately between Latitude 4^{0}30`N–5$^0$50`N and Longitude 5^{0}05`E– 6$^0$41`E, with high average annual precipitation of about 1900 mm and elevation of 280 m as shown in Figure 1.With mean annual temperatures range from about 22^{0}C to 34^{0}C, and rainfall is between 1,501 mm to 1850 mm; mean evapotranspiration is 1117 mm [41,42]. According to [20] the study area is < than 6 m above Sea Level (SL) in the lowlands that adjoin the sea, to heights > than 280 m above SL in the plateau that defines the northern fringe of the state see (Figure 1). The vegetation of study area varies from salt water swamp within the coastal area adjoining the sea to rain forest towards the northern portions of the state [20]. [6] were of the view that the geomorphology of the study area is sub-divided into marine environment namely: continental, transitional and marine environments. [43,44] sub-divided geomorphological unit of the study area into five categories:

i. Abandoned and active coastal beaches;

ii. Dry flat land and plain;

iii. Back-swamps deltaic plan, freshwater swamps, alluvium and meander belt;

iv. Salt water mangrove swamps;

v. Dry deltaic plan with abundant swamp zones;

vi. Sombreiro Warri plain;

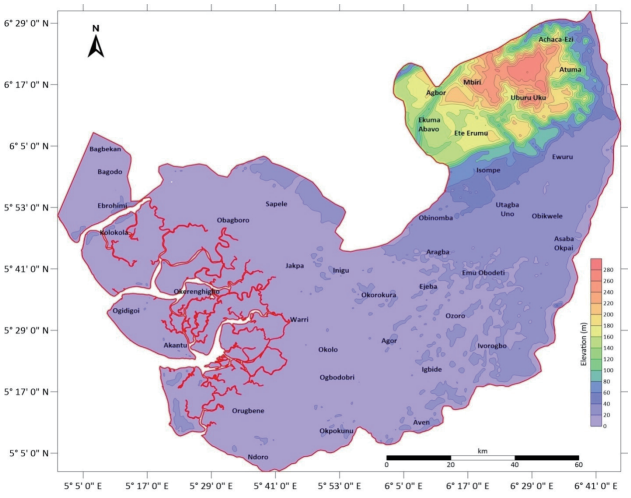

Figure 1. Physiographic Map of Delta State

2.2 Geology/Hydrogeology of the Study Area

The study area lies within the Niger Delta Basin with different formations as shown in Table 1.

i. The Akata Formation overlies the Agbada Formation it composed of continuous shale and about 10% sandstone [6]. There has been reported the shale of Akata Formation is believed to be over pressured and under compacted. It ranges from Eocene to Recent and was deposited under marine conditions.

ii. The Agbada Formation conformably overlies the Akata Formation in the subsurface. It consists of parallel alternating sequence of shale and sandstone with age ranging from Eocene in the northern part to Pliocene/ Pleistocene in the southern part, and Recent in the delta surface. Its lateral equivalents at the surface are the Ogwashi-Asaba Formation and Ameki Formation of Eocene- Oligocene age. The Ogwashi-Asaba Formation constitutes the main rock outcrops in the Asaba Capital Territory.

iii. The continental Miocene-Recent, the Benin Formation is of Miocene to Recent in age and conformably overlies the Agbada Formation. The formation comprises largely of sand with less shale/clay. They are also poorly-sorted, sub-angular to well-rounded, and bear lignite streaks and wood fragments. The Benin Formation occurs just west and northwest of Asaba town [42] and this extends into Agbor town. The west and south of Abraka alongside Sapele, Warri and Ughelli the Benin Formation is masked by the younger Holocene deposits of the Sombreiro-Warri Deltaic Plain, the Mangrove Swamp and Freshwater Swamp wetlands. These aforementioned deposit have not assigned formally to geological names based on the fact that universally they are considered to be recent expressions of the continuation of the Benin Formation are only identified by the physiographic terrains in which they occur. The aerial distribution of these delta top deposits coincides somewhat with the associated physiographic subdivisions shown in Figure 1.

Table 1. Geological sequence of Delta State (modified after [45])

Formation		Age
Deltaic Plain Sediments		Late Pleistocene-Holocene
Benin Formation		Oligocene-Pleistocene
Agbada Formation	Ogwashi-Asaba Formation	Oligocene-miocene
Akata Formation	Ameki Formation	Eocene

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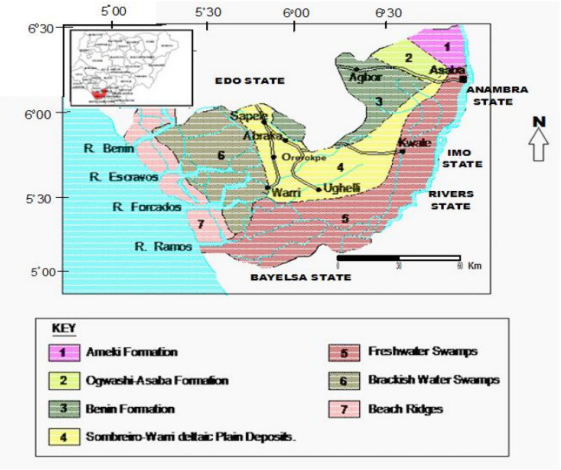

Figure 2. Geological Map of Delta State (modified from [42])

3. Overview of Water Resources Potential of Delta State

3.1 Surface Water Resources

The study area is highly blessed with surface water especially along the south-eastern area, and along the creek and coastal regions. Several authors have reported that one of the major challenges of surface water in the study area is seawater intrusion [18,27,4]. The study have alot of rivers and streams such as Ughelli River, Agbarho River, Okpare River, Forcardos River Ughewhe stream Egbo stream, Olomoro stream, Ekpan river, Ekuredeitsek, Jeddo river, Eja-etan river, Ubeji creek, Ifie-kporo river and many other that drain into River Niger and Atlantic ocean. [6] were of the same view that intense rainfall has resulted in surface runoff, especially along the NE region of the study area. These runoffs often drain into the River Niger, while some gathers in pools, evaporate or infiltrates into the ground, as direct recharge. The River Niger and Asaba Plateau, with its undulating slopes dominate the Asaba landscape (see Figure 1).

3.2 Groundwater Resources

[46], reported that water typically penetrate the subsurface through percolation from surface water bodies, precipitation and infiltrating. [6] reported that over 90 % of the potable water needs of the state are obtained from shallow aquifers by the use of shallow tube and hand dug wells. Previous studies revealed aquifer as easily prone to chemical and microbial contamination based on the fact that they occur few meters below the earth surface [6,20,11,47]. Similarly, studies revealed that the closeness to the sea makes saltwater contamination of the aquifer a permanent threat [48]. Groundwater occurs in all the geological formations was described in the older terrace deposits, the Ogwashi-Asaba Formation and the deeper Ameki Formation. The first aquifer comprises of the terrace deposits and the underlying upper horizons of the Ogwashi-Asaba Formation. The second and deeper aquifer comprises of the sand horizons of the Ogwashi-Asaba Formation. [49], reported that elsewhere in Delta state (Abraka, Ughelli, Warri and Sapele), water table conditions prevail in the area and that the depth to water varies within Abraka inland from about 4 to 26 m, south east part of Delta state. [6] acknowledge that the Ameki Formation is considered too deep in this area which makes it not economically viable aquifer. This has led to the fact that no successful boreholes has been drilled it Ameki Formation to its deep range. Findings from [42] further revealed that majority of boreholes in Asaba obtain water from the shallow old terrace alluvium.

4. Methodology and Data Gathering

In the current study, information related to this study was the source for using google search engine. Published articles on water resources and bacteriological assessment of water quality in Delta state, Nigeria between last few decades were downloaded and reviewed. These relevant papers were thoroughly studied and findings from the paper were carefully presented in tabular form with details of publication particulars, study location, period, approach, methodology as shown in Table.1. Assessment of water resources quality is based on the following:

i. Hydrogeochemical assessment
ii. Microbial assessment

5. Results and Discussions

Table 1 below presents brief information on hydrochemical and microbial status of water resources of Delta State.

5.1 Hydrogeochemical Assessment

The extensive human activities in the study area, have led to a series of water resource pollution. Various human activities have altered the hydrochemistry of water as captured in various publications and commentaries. Water resource pollution is considered as a major threat to human life and aquatic organism. Having established the fact in the introductory part of the paper that the water resources of the study area is moderately to highly polluted in some areas to the extent of not being potable due to area-specific anthropogenic influences. It was considered imperative to review the extent of pollution and, if possible, quantify

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Table 1. Brief information on water resources in Delta State

Water Type	Location	Key findings		References
		Hydrochemical	Microbial	
GW	Sapele metropolis, Ajogodo, Ogorode, Okirighwre and Ugberikoko	Fe, Cr, and pH were above WHO Set limit	Nil	[50]
SW, GW and Harvested Rain water	Ughelli		Nil	[51]
GW	Sapele	Temperature was below set standard high Ec	Nil	[52]
SW and GW	Agbahra, Otovwodo, Evwreni, Afiesere, Orhuwhorum, Utorogu, Akperhe, Eruemuhohworien, And Ovhori,	Alkali bicarbonate water type is the dominant ionic specie with HCO_3 as the predominant ion. Contaminant in Water resources Was traced to human activities such as septic tanks, pit latrine	There was presence of *E.col* in GW sample studied.	[15]
GW	Sapele	Chloride ion is dominant Physicochemical parameters were below the set limit	Nil	[52]
SW	Warri	Anthropogenic influenced Sample water Pb, Cd and Cu were above Set limit	Nil	[54]
GW	Orerokpe	Rock-Water interaction is the major factor that influences GW	Nil	[47]
GW	Boji Boji Agbor, Alihami, Boji Boji Owa, Agbor Obi, Owa Alero	Ec, pH TDS, Temp and COD were Relatively low.	Nil	[55]
GW	Jeddo, Olugbo-odo, Obodo, Ikoto, Osele and Lodu Imenyi	Groundwater showed effect of corrosion. Slightly affected by Salinization	Nil	[27]
GW	Isiokolo, Apkerphe, Evwreni, Ovhori, Ughelli, Oferokpe and Agbraha	Precipitation has influence on groundwater quality, Groundwater showed slight presence of sea water intrusion.	Nil	[26]
GW	Agbor-nta, Owa Oyibu,	Major factors that influences GW Water-soil interaction Pollution related to biochemical Dominant Cl ion as a result of Base exchange reaction	Aerobic bacteria counts 5 - 535cfu/ml and total coliform (10 - 70MPN/100ml	[56]
SW	Agbor, Owa,			[57]
GW	Obiaruku, Okuzu	Groundwater was considered unsuitable for drinking and other purpose		[58]
GW	Warri	Major factors that influence water Rock-weathering Human activities High TDS, Pb, Ci, Ni and Cl Slight seawater intrusion	Fecal Colioform Above set limit	[59]
SW	Kokori-Erhoike	High TS, Ec, Ca, Mg,PO^{3-}	Nil	[60]
GW	Warri	Groundwater was considered Acidity		[19]
GW	Ozoro	High concentration of Cu	Nil	[61]
GW & SW	Ubeji, Ejeba, Jakpa, Airport Junction, Udu Road,Okumagba Avenue, Esisi road and Warri River	Geogenic and anthropogenic activities played a major role in water quality	Nil	[62]
GW	Boji Boji Agbor, Alihami, Boji Boji Owa, Agbor Obi, Owa Alero	Slightly high concentrations of Ca, SO_4^{2-}, Na^+ and PO^{3-}	Nil	[63]
GW	Ekrebe Unuode, Okotie, street, Okan, Akpovi Avenue, Agbraho, Oboru Akpoguma and Ekrerhervwe	Hydrochemical facies: $MgCl_2$ and NaCl facies Major factor influencing GW is precipitation Parameters were below set Standard	Coliform Faecal coliform	[28]
GW	Agbor	Pb and pH were above set limit	No significance Coliform	[64]
GW	Burutu	Analyzed parameters were Slightly above set limit. The is Presence of seawater intrusion		[65]
GW	Delta state	Chloride water type (sea water Intrusion), low pH	Coliform bacteria and *Enterococcus faecalis*	[20]
GW & SW	Opuraja Community	acidic pH	*Vibrio* sp., *Escherichia coli*, *Salmonella* sp., *Shigella* sp	[66]
GW	Amba, Okorodudu, Low Beach, Quarters, Court road all in Burutu		Coliforms were above permissible limit	[67]
GW	Udu		Coliforms were above permissible limit	[68]

Where: GW= Groundwater, SW=Surface water

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Table 2. Source of various ions in water resources, and attendant health implications

Major ions	Possible sources of the various Ions	Health Implications
Na	• Leachate from landfill and garbage dumps located in the SE part of the area • leakages from septic tanks in densely populated area • Animal waste	Excess Na causes hypertension, congenial diseases, kidney disorders and nervous disorders in human body [69]
Cl	• Cl in water originates from industrial effluents, sewage and urban runoff that contain saline intrusion • Sewage discharges and leakages in the densely populated area • Leakage from septic tanks • Leachate from landfill and garbage dumps • Waste from animals generated along river side	Excess Cl in water such as hypertension, chances of stroke, ventricular hypertrophy, osteoporosis, renal stones, and asthma ([70]; [71])
K	• Fertilizer application • Landfill leachates • Animal waste and leakage from septic tanks	Presence of K in water may lead to kidney disease, heart disease, coronary artery disease, hypertension, diabetes, and adrenal insufficiency
HCO_3	• Sewage waste and landfill leachate	
Nickel	• Smelting • Refining and petroleum industries • Chemical and catalyst production	Possible carcinogen
NO_3	• Septic tank over flow and leakages • organic and chemical fertilizers	High concentration of NO_3 in water may lead to gastric cancer, goiter, birth malformation and hypertension
SO_4	• Application of fertilizer • Wide application of H_2SO_4 in electroplating • Anthropogenic sulfur emissions from fossil fuel combustion may also contribute to the overall SO_4 concentrations in groundwater	High SO4 such as dehydration, catharsis, gastrointestinal irritation and diarrhea.
Mg	• Discharge and emissions from industries that use or manufacture magnesium. • The concentration of Mg in river and sea water can be increased by rainwater falling on rocks	High concentration of Mg in water may lead to the damage of gastrointestinal tract, nervous system and the kidneys.
Ca	• Occur as result of soluble and abundance in most rock types	High concentration of Ca in water may lead to hypercalcaemia, metabolic alkalosis and renal insufficiency) and hypercalcaemia.
Pb	• The amount of dissolved lead in surface water and groundwater depends on pH and the concentration of dissolved salts • And the types of mineral surfaces present	The presence of Pb in water may lead to tiredness, sleeplessness, irritability, headaches, joint pain and gastrointestinal.
Fe	• Possibly due to industrial activities, refuse dumps and metal scraps along the river courses, which are also sources of groundwater	Excess Fe in water when taken by human may lead to genetic disorder, depression, rapid and shallow respiration, coma, convulsions, respiratory failure, and cardiac arrest
Zn	• It may be due to industrial activities, refuse dumps and metal scraps • along the river courses which are also source of groundwater	High concentration of zinc in water can lead to nausea, stomach cramps and vomiting.
Cu	• It may be due to industrial activities, refuse dumps and metal scraps • along the river courses which are also source of groundwater	Excess Cu in water may lead to nausea, vomiting, stomach cramps or diarrhea, it can further cause damage to kidney and liver in human
Mn	• Manganese often occurs naturally together, through the weathering of rocks and minerals, may also be present in underground water due pollution sources	Excessive intake of manganese in water may lead to neurological disorder
Cr	• The major sources of Cr in water is releases from electroplating processes and the disposal of chromium containing wastes	High intake of chromium may lead to carcinogenic disease
Ec	• Water drained from agricultural fields, municipal waste water, rainfall	The higher Ec may cause a gastrointestinal irritation in human beings.
pH	• Low pH- Acid rain as a result of gas flaring • pH above 8.5 is regarded as hard water.	i. Hard water does not pose a health risk, but can cause aesthetic problems Though pH has no direct effect on human health, all biogeochemical reactions are sensitive to variation of pH. ii. Hard water does not pose a health risk, but can cause aesthetic problems

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it. Most of the activities are in one way or the other connected to modern day development, unlike in decades ago were the quality of water resource was considered fit for various purpose. [28] were of the view that major cations were below maximum permissible limits within the Sombreiro-Warri plains, Warri Delta state. They further stated that the depth to water level within the Sombreiro-Warri plains varies from 1.2 to 6.45 m. [62] pointed out that within the Sombreiro-Warri Deltaic plain sands Cl concentration in groundwater fall below saltwater intrusion bench mark of 130 mg/l, according to [72]. Although, [26] pointed out that chloride is also a reliable tool for judgment on saltwater intrusion because it is the most stable macro element in seawater and the most sensitive to saltwater intrusion. Klassen, et al., (2014) were of the opinion that when chloride content greater than 130-484.0 mg/l in groundwater is 90-95% indication of saltwater intrusion. Studies have shown that there is presence of high chloride concentration is an indication of salt water contamination in Niger Delta Region [26,27,73,74]. They went further to point out that it implies the absence of marine influence on groundwater within Warri, Delta state, although their findings contradict report from [59] which was of the view that the Nacl water type in the Warri area suggests possible salinization of groundwater within the Sombreiro-Warri Deltaic plain sands. [59] went further to prove fact that $NaHCO_3$ type does not exist within Warri. His results implies that salinitization in the study area is caused mainly by recent sea water intrusion. Findings from [59]; [16] suggested that the groundwater within the Sombreiro-Warri Deltaic plain sands is considered fresh water type based on total dissolved solid assessment. [59] further reported that three groups of groundwater types exist within the Sombreiro-Warri Deltaic plain sands in Warri, Delta state namely: calcium bicarbonate water type, calcium chloride water type and sodium chloride water type. He further acknowledges that the calcium bicarbonate water type reflects groundwater zone that is characterized with low electrical conductivity (Ec) and TDS. While the sodium chloride water type reflects groundwater of the discharge zone area that is generally characterized with high Ec and TDS. The calcium chloride water type is the transition zone between the two water types. From his findings it was observed that the Nacl water type is water type close to the sea shore, while the calcium carbonate water type is confined within the hinter lands. [59] was of the opinion that salt water intrusion plays a major role in groundwater geochemistry of groundwater around the sea shore. From total dissolved solid and Chadba's plot suggested that water fell within the four categories, namely soft, moderately hard, hard and very hard [59,27,75] evaluated hand dug wells from different locations in Agbarho in Delta state, findings from the study suggested that SO_4, Cl, Cu, Fe, Pb, NO_3, Cr, Zn, Na, Mn and K were below WHO permissible limit. Hence, result from the study revealed that groundwater is fit for domestic use and that anthropogenic activities within the area have no strong influence on groundwater within Agbarho community in Delta state. [24] were of the same view with [75] that Pb concentration in groundwater within the part of Warri metropolis was found to be below WHO permissible limit. Studies from [28] on heavy metals such as Pb, Cd and Cr in groundwater within Agbarho, Delta and were compared to MPLs set by SON result from their study suggested that aforementioned heavy metals were below the set limit. Further findings from [28] which suggested that Pb, Cr and Cd were below detection limit in groundwater in Sombreiro-Warri Deltaic Plain Deposit of Agbarho, Delta state. Although studies from other scholars suggested that Pb, Cr and Cd concentration was detected in water in Warri, Delta state [76,77]. [24] reported that pH of groundwater within these towns; Ekpan, Mosogar, Agbor and Adeje site all located in Delta state were considered to be acidic based on pH values obtained from groundwater samples. From the pH values one could suggest low pH (acidic water) may possibly trigger corrosion in groundwater. In the same vein, [26]; [18] were of the view that 96.3 % groundwater within some selected towns and village such: Akpkerhe, Ovhori, Evwreni, Agbarha, Isiokolo, Orerokpe and Ughelli fell within the acidic water based on pH value obtained from their study, the effect of low pH in groundwater could be seen in Table 2. The acidity of groundwater within this area could be attributed to precipitates acid rain in the region acid rain [78, 12]. The occurrence of acid rain in the Niger Delta region of Nigeria has been studied by various authors in the past [78,79,80,12]. Aside anthropogenic activities that influence water quality. The controlling effect of geology on groundwater occurrence in Niger Delta is no longer in doubt, as its influences the geochemistry of groundwater [26]. [26] reported that Gibbs plot from studied groundwater in around community and towns in Delta state aforementioned suggested that precipitation is major process that influence groundwater. This is in line with reports by several author as mentioned above. [27] suggested that groundwater within the Sombreiro-Warri plains was considered fresh water based on TDS values obtained from groundwater. Although result from their study showed variation in TDS, the sources of material in TDS may come from nature, i.e. geological condition and seawater, and from human activities, i.e. domestic and industrial waste and also agriculture [48]. [81] reported that variation in TDS values may also occur due to geogenic activities of a particular region. [82] were of

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the view that the sedimentation pattern as well as stratification determines both the quality and quantity of water in the region. [47] reported that ground water in Orerokpe, Delta state was considered soft and its chemical composition is being influenced mainly by geogenic factors which is accelerated by the mildly acidic nature of recharging rainfall. [83] further suggested that whenever water is contaminated it adverse effect is shown on human health, domestic and industrial development, survival of lives which serve as a source of food for humans. Thus their impacts could be severe depending on the constituents of such wastes. According to [74] the source of most of the hydrogeochemical parameters in the water in the area is dissolution from the rocks as the water percolates underground. However, percolation and geochemical processes within the groundwater system also account for some of the high concentrations in physicochemical parameters.

5.2 Influence of Microbial Organism on Water Resources

Microbial studies in water resources are scanty in literature within the study area. Unsanitary water has particularly devastating effects on young children and adults in most developing world, including Nigeria. Several scholars reported that wells situated in highly populated area are in most cases cited close to domestic refuse dumps, pit latrines and stagnant waters and drainages [31,56,67]. According to [18], the total coliform bacteria and faecal coliform have the highest mean values in river are greater than open well and not in rainwater in the region. They further reported that presence of open wells and river water resources in the creek/riverine communities especially makes water vulnerable to microbial/pathogenic organisms, and makes these water sources of low quality for domestic uses. However [66] reported that several infectious diseases are transmitted via water through the fecal-oral route. Although, several authors consider *E faecalis* to be a good indicator of faecal pollution because of their greater resistance than coliforms to environmental pressure. The presence of these faecal coliforms in some of the water resources suggests that these coliform bacteria in water indicate that the water has been contaminated with fecal material of man or other animals. [75] report that groundwater studied at Akpiroroh, Erhidi, Abavo, Oguname, Ahirim show no trace of coliform, while that of Oseri, Uvwiamughe, Idirima, Urhoboghara and Ogubane were contaminated with coliform bacteria, and those of Ogubane showed the highest coliform count, this may be attributed to the fact that there might of presence of pit latrine and also practice open defecation. [59] reported that groundwater within Sombreiro-Warri Deltaic plain, Warri Delta states showed fecal coliform that are higher in concentration, above the stipulated WHO permissible limit. [20] suggested that shallow aquifer is more vulnerable to contamination of all kind. [68] reported that groundwater samples analyzed at Udu community in Delta state showed the presence of bacterial counts which were probably obtained from environmental sources, and were far above [39,40] allowable limits. They further attributed the occurrence of high coliform populations in all the water samples is an indication of poor sanitary conditions in the community. The [84] guideline stipulated a coliform count of zero (0) per 100 ml. Total Coliform organisms per 100 ml are an indication of some degree of contamination. Findings from [67,82,85,86,14] showed striking similarity that groundwater resource in Burutu Warri, Amai kingdom and Ughelli respectively showed all forms of coliform that were far above [39] standard. This may be attributed to the facts that well are cited close to septic tanks, open defecation and pit latrine are practically been practiced by people of the area.

6. Concluding Remarks and Recommendations

6.1 Concluding Remarks

On a general note water of good quality is needed for healthy life, but with a steady increase in water pollution. It is necessary to know the quality of water used by human being has become a serious issue in past years [87]. As water of good quality for human continues to receive the attention of government agencies, academics and health services, institutions and non-government organization. Report by WHO clearly stated the world is currently facing water crisis. The assessment of water quality is highly needed, however, is very costly and the government agencies would rather live in denial, take the goodness of the quality of water being consumed by the citizens as fore-granted even if the contrary is true. However findings from the study, revealed that groundwater is more studied compared to surface water. Most of the researches carried out on water resources quality assessment were carried out across the study area exception of north-east part of the study area. As mentioned by several scholars, acid-rain is one of the major problems that affect groundwater pH especially along the oil producing area of the state. Findings from the study showed that groundwater chemistry is influenced dominantly by rock weathering and precipitation processes. The differences in concentrations of the various ions in the groundwater may be linked to the amounts of ions in the rock matrix, reaction characteristics and transport history. From findings, it was observed that large

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percentage of groundwater samples have fecal coliform. Lastly, findings from this reviewed literature showed that decline in water quality is considered dangerous to human and animal.

6.2 Recommendation

The government should set up relevant bodies that will enforce strict measures to ensure good water quality available for the people of Delta state especially the people living around the creeks and rural communities and there should be sensitization on effect of oil spillage on water resources. This could help to mitigate the current irregularities in the quality of commercially accessible water. It is further recommended that:

• It will be better off if water storage tanks are non-metallic to avoid corrosion.

• The inhabitants of the study area should be educated on the danger of their act in respect to the way sewage is disposed and related diseases that accompany the act is therefore advocated

• It is necessary for water to be thoroughly treated before usage.

• Water exploration should leave in hand of state and federal government especially within rural communities.

• Microbial treatment should be carried out on water resources before consumption

• Wells should be located far from domestic refuse waste, pit latrine, stagnant water and drainages

• Reasonable amount of money should be allocated by state and federal government for improvement of public water.

Finally, in other to improve quality for water resources for domestic and other use, it is recommended that government and private partnership are highly needed such that water management plants be set up in most urban and suburban locations to ensure the availability of pipe-borne water.

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ARTICLE

Quantum Biophysics of the Atmosphere: Factor Analysis of the Annual Dynamics of Maximum, Minimum and Average Temperatures from 1879 to 2017 to Hadley English Temperature Center (Hadcet)

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ABSTRACT

Factor analysis of annual dynamics from 1879 to 2017 was carried out by the method of identification of stable regularities: maximum, minimum and average air temperature of Central England according to HadCET. The sample capacity was 139 rows. In factor analysis, time is excluded, and it acts only as a system-forming factor that ensures the relationship between the three parameters of climate and weather. Therefore, the adequacy of the dynamics models is taken into account in the diagonal cells of the correlation matrix. In addition to time, different lists of objects are possible in factor analysis. The coefficient of correlation variation, that is, a measure of the functional relationship between the parameters of the system (annual weather at the weather station in Central England) is 0.8230 for trends, 0.8603 taking into account the annual dynamics of the four-membered model obtained from the computational capabilities of the software environment CurveExpert-1.40, and 0.9578 for the full up to the error of measurement wavelet analysis of the dynamics of the values of three factors. In all three methods of factor analysis, the meteorological parameter «average Annual temperature» was in the first place as the influencing variable, the «Maximum temperature» was in the second place, and the «Minimum temperature» was in the third place. As the dependent measure in these areas there are three kinds of temperature. The comparison shows that among the binary relations between the three temperatures, the average temperature on the maximum air temperature in the surface layer of the atmosphere has the greatest influence on the correlation coefficient 0.9765. At the same time, all six equations refer to strong connections, so there is a high quantum certainty between the three types of temperature. But when predicting the most meaningful essence showed the maximum temperature.

1. Introduction

At various points of the Earth, meteorological stations have accumulated many time series, for example, the temperature of the air in the surface layer. According to Hadcetma processed the series of maximum, minimum and average annual temperature of Central England. In this paper, we combine these three parameters and show the method of factor analysis. In the future, the number of

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factors can be increased to 25-50, including meteorological data of land, ocean, stratosphere and troposphere and other objects.

In factor analysis, each binary relation contains a trend and a set of wavelet signals. Moreover, the trend is a special case of a super-long wavelet oscillation period. As a result, the General statistical model of dynamics is a bundle consisting of a set of solitary waves (wavelets) with variable amplitude and oscillation period. After statistical modeling of rank (instead of dynamic series, for example, on the list of objects included in the system) and binary distributions, factor analysis is carried out on the adequacy of monar (in the diagonal cells of the correlation matrix) and binary relations, which allows to make ratings of factors as influencing parameters and as dependent indicators on the values of the correlation coefficient.

The proposed methodology for the identification of clearly nonlinear stable regularities [4-11] allows us to distinguish the waves of monarch and binary relations between all measured and considered factors, which can be compared with heuristic representations of specialists in the study and management of climate and weather.

Therefore, the practical application of our methodology involves iterative identification, at least every year (and for monthly data every month). At the same time, each time an approximate forecast is made for the length of the forecast horizon equal to the base of the forecast. The identification method allows to identify the most significant parameters of the studied system of any kind and strong binary relations between them, which will need to further improve the accuracy and speed of future measurements.

Our method of identification of the general wavelet equation (solitary wave) from the measured statistics will complement and refine the climate mitigation scenarios up to 2100 described in article [1].

However, we believe that according to the available dynamic series. Other scientists have not been able to identify wave patterns so far. Therefore, climatologists and meteorologists have taken the path of simplifying time series. This is manifested in the fact that the indicators are grouped data, for example, moving average for periods of 10 years, and only linear or linearized models are used.

The water regime of meadows [4] and carbon dynamics in Europe [6,7] change according to wavelets of universal design [5].

Then we distinguish two types of quanta of behavior:

First, in dynamics, each factor is divided into the sum of wavelets, that is, in time, the factor is represented as a bundle of solitary waves (solitons) and this process is characterized as *quantum unraveling*;

Secondly, the mutual influence of the above three factors with uniform or uneven periodicity of measurements additionally obtains quantum entanglement in some boundaries.

Thus, any phenomenon or process can be estimated by the level of adequacy (correlation coefficient) of decomposition of the functional connectivity of the system into quantum entanglement and quantum entanglement.

It turned out that in quantum meteorology [8,10] can distinguish the quantum fitopatologia [9,11] for vegetation period of plants.

Plant growth is a complex process. In the process of plant ontogenesis growth is observed during the main stages of its life cycle [14-16]. Therefore, in further studies it is possible to identify patterns of influence of meteorological parameters on the dynamics of vegetative organs of plants.

2. Source Data

Data on three types of air temperature in the surface layer are given in Table 1 (ssn_HadCET_max.txt, ssn_HadCET_min.txt, ssn_HadCET_mean.txt).the data are described in articles [2,3,12.13]. For the beginning τ=0 of the reference dynamics was adopted in 1879, and for the end of the measurement time – 2017. In all known time series apply a uniform scale. Table 1 is no exception. However, non-uniform time scales can be used, for example, with omissions, which significantly increases the predictive capabilities of our method for identifying stable patterns [5].

Table 1. Maximum, minimum and average annual temperatures

Year	Time τ, years	Air temperature, ^{0}C		
		maximum t_{max}	minimum t_{min}	average $\bar{t}$
1879	0	10.52	4.36	7.44
1880	1	12.54	5.63	9.10
1881	2	12.12	5.03	8.58
1882	3	12.99	5.94	9.47
1883	4	12.70	5.38	9.04
2013	134	13.29	5.92	9.61
2014	135	14.75	7.15	10.95
2015	136	14.17	6.45	10.31
2016	137	14.18	6.51	10.34
2017	138	14.30	6.87	10.58

(according to the Headset from 1879 to 2017)

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When analyzing the factors time is excluded, and it acts only as a strategic factor that provides the relationship between ramapura-metriclima and weather. Therefore, the adequacy of the dynamics models is taken into account in the diagonal cells of the correlation matrix. In addition to time, different lists of objects are possible in factor analysis.

3. Wave and Trend Identification

Wavelet signal, as a rule, of any nature (object of study) is mathematically recorded by the wave formula [5] of the form

$$y_i = A_i \cos(\pi x / p_i - a_{8i}),$$
$$A_i = a_{1i} x^{a_{2i}} \exp(-a_{3i} x^{a_{4i}}),$$
$$p_i = a_{5i} + a_{6i} x^{a_{7i}}, \quad (1)$$

where y– the index (dependent factor), i – the number of the component model (1), m – number of members in the model (1), x – explanatory variable (influencing factor), $a_1 ... a_8$ – the parameters of the model (1) taking the numerical values in the course of structural-parametric identification in the software environment CurveExpert-1.40 (URL: http://www.curveexpert.net/), A_i – amplitude (half) of the wavelet (axis y), p_i – half-period of oscillation (axis x).

According to the formula (1) with two *fundamental physical constants e* (the Neper number or the number of time) and π (the Archimedes number or the number of space), a *quantized wavelet signal* is formed from within the phenomenon and/or process under study. The concept of wavelet signal allows us to abstract from the physical meaning of many statistical series of measurements and consider their additive decomposition into components in the form of a sum of individual wavelets.

A signal is a material carrier of information. And we understand information as *a measure of interaction*. A signal can be generated, but its reception is not required. A signal can be any physical process or part of it. It turns out that the change in the set of unknown signals has long been known, for example, through the series of three-hour meteorological measurements. However, there are still no statistical models of both dynamics and mutual connection between the four weather parameters at this weather station.

The trend is formed when the period of oscillation a_{5ii} tends to infinity. Most often, the trend is formed from two members of the formula (1).

All models in this paper have been identified in the special case where the model parameter a_2=0, by a two-term formula

$$y = a \exp\left(-bx^c\right) + dx^e \exp\left(-fx^g\right) \quad (2)$$

where y – the dependent measure, x – influencing variable, a–g – model parameters (2) identified in the software environment CurveExpert-1.40.

4. Factor Analysis Identification of the Trend

Table 2 shows the *correlation matrix* of binary relations and the rating of three factors obtained by the identification method [5] according to Table 1. In our example, in the diagonal cells we put the correlation coefficient of the trend according to the dynamics models from 1879 to 2017.

Table 2. Correlation matrix of factor analysis and factor rating after the identification patterns of the trend (2)

Influencing factors (characteristic x)	Dependent factors (indicators y)			Amount $\sum r$	Place I_x
	t_{max}, °C	t_{min}, °C	$\bar{t}$, °C		
Maximum temperature t_{max}, °C	0.6086	0.8733	0.9760	2,4579	2
Minimum temperature t_{min}, °C	0.8761	0.5618	0.9590	2,3969	3
Annual mean temperature $\bar{t}$, °C	0.9765	0.9592	0.6168	2,5525	1
The sum of the correlation coefficients $\sum r$	2,4612	2,3943	2,5518	7,4073	-
Place I_y	3	2	1	-	0.8230

The coefficient of correlation variation, that is, a measure of the functional relationship between the parameters of the system (annual weather at the weather station), is equal to $7.4073 / 3^2 = 0.8230$. As the influencing variable at the first place was the meteorological parameter «Annual mean temperature», the second «Maximum temperature» and in third place – «Minimum temperature». As the dependent measure in these areas there are three kinds of temperature.

In total, there were six strong regularities according to the formula (2) with a mutual relationship between the temperatures with a correlation coefficient of not less than 0.7. Diagonally turned trends with adequacy 0.5-0.7 average.

5. Factor Analysis by Identification of the Wave Equation

At the information technology level, the 23rd Hilbert problem (development of methods of variational calculus) was solved by us [5].

At the same time, *the variation of functions* is reduced to the conscious selection of stable laws and the construction of adequate stable laws on their basis. We adhere to the concept of Descartes on the need to apply an algebraic equation of General form directly as a finite mathematical

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solution of unknown differential or integral equations. A new class of wave functions (1) was proposed for this purpose.

The concept of vibrational adaptation in nature suggests that between the selected factors in Table 1. There are dependencies in the form of wave equations. However, it turned out that there is no wave connection between these three factors, which indicates the presence of quantum entanglement of meteorological data. Only the dynamics of the 139 Lettre parameters allow the identification of many wavelets. Four terms of equation (1) were jointly identified by the computational capabilities of the software environment CurveExpert-1.40.

The adequacy of the models in Table 3 is given by four members of the general model (1), containing one or two trend members (2) and two or three wave-equinox dynamics for the diagonal cells of the correlation matrix.

Table 3. Correlation matrix of factor analysis and factor rating after trend (2) identification of binary wavelet relations (1) dynamics

Influencing factors (characteristic x)	Dependent factors (indicators y)			Amount $\sum r$	Place I_x
	t_{max}, °C	t_{min}, °C	$\bar{t}$, °C		
Maximum temperature t_{max}, °C	0.7011	0.8733	0.9760	2,5504	2
Minimum temperature t_{min}, °C	0.8761	0.7131	0.9590	2,5482	3
Annual mean temperature $\bar{t}$, °C	0.9765	0.9592	0.7086	2,6443	1
The sum of the correlation coefficients $\sum r$	2,5537	2,5456	2,6436	7,7429	-
Place I_y	2	3	1	-	0.8603

The coefficient of correlation variation is 7.7429 / 32 = 0.8603.The rating of influencing and dependent factors in comparison with Table 2 has not changed.

Previously it was shown that up to errors of measurement of temperature it is possible to carry out the wavelet analysis. For the maximum temperature, 57 members were obtained, for the minimum temperature, 64, and for the average annual temperature, 188 members. Then practically the correlation coefficient will rise to 1 (Table 4).

Table 4. Correlation matrix of factor analysis and factor rating trend (2) for binary relations and wavelet set (1) dynamics

Influencing factors (characteristic x)	Dependent factors (indicators y)			Amount $\sum r$	Place I_x
	t_{max}, °C	t_{min}, °C	$\bar{t}$, °C		
Maximum temperature t_{max}, °C	1	0.8733	0.9760	2,8493	2
Minimum temperature t_{min}, °C	0.8761	1	0.9590	2,8351	3
Annual mean temperature $\bar{t}$, °C	0.9765	0.9592	1	2,9357	1
The sum of the correlation coefficients $\sum r$	2,8526	2,8325	2,9350	8,6201	-
Place I_y	2	3	1	-	0.9578

The coefficient of correlation variation became equal to 0.9578 and the rating of influencing and dependent factors in comparison with Table 2 and 3 did not change.

If the remains after the wavelet analysis are not further modeled, then experts say about some noise. But we believe that noise can only be called residues that are

Table 5. The parameters of models of the dynamics of the meteorological data in Table 1

Number i	Wavelet $y_i = a_{1i}x^{a_{2i}} \exp(-a_{3i}x^{a_{4i}})\cos(\pi x / (a_{5i} + a_{6i}x^{a_{7i}}) - a_{8i})$								coef. corr. r
	The amplitude (half) the fluctuations				The half-period of oscillations			Shift	
	a_{1i}	a_{2i}	a_{3i}	a_{4i}	a_{5i}	a_{6i}	a_{7i}	a_{8i}	
Maximum air temperature dynamics									
1	9.75509	0	0.32695	0.39408	0	0	0	0	0.7011
2	4.76899	0.20451	0	0	0	0	0	0	
3	0.60554	0	0.00067008	1.30655	331.51060	-2.16881	1.00023	-0.15038	
4	0.44184	0	0.037403	0.75225	7.11016	-0.00096285	1.50572	1.66394	
Minimum air temperature dynamics									
1	4.47820	0	-0.10237	0.22512	0	0	0	0	0.7131
2	0.11964	0	-0.0086459	1	3.82002	0.50590	0.71167	1.65200	
3	-0.17853	0	-7.95574e-6	2.26277	3.65855	0.014686	0.54239	-0.10801	
4	0.049902	0	-0.0016021	1.43297	11.44579	0.037200	0.60525	5.90933	
Dynamics of average annual air temperature									
1	8.34895	0	0.00083403	1.44674	0	0	0	0	0.7086
2	0.069430	0.94925	0	0	0	0	0	0	
3	-0.070861	0	-0.47413	0.25105	218.12924	-0.24701	1.34031	-3.30961	
4	4.05019	0	1.35915	0.22971	6.27630	0.00042187	2.55027	1.81124	

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equal to or less than the measurement error. Therefore, part of the noise exceeding the measurement error should be attributed to quantum entanglement. And the share of parameter values determined by the revealed regularities should be attributed to *quantum unraveling*.

6. Regularities of Air Temperature Dynamics

Table 5 shows the values of the model parameters (1). It shows that parts of the trend are special cases of the General wavelet.

Let's take dynamic models containing four terms (one-two for a trend and two-three asymmetric wavelets). As a rule, models of any dynamics (at different time counts: year, month, day, hours, minutes) can be brought to a finite set of wavelet signals by identification method. The criterion for stopping the identification process is only the measurement error. Each wavelet thus becomes a separate quantum of behavior (the structure of macro-objects in comparison with their behavior can be taken constant). For example, the average air temperature in Central England for the years 1659-2017 according to Hadley-CentreCentralEnglandTemperature (HadCET) before the measurement error ^{0}C is characterized by a set of 188 wavelets.

A negative sign in front of the model component indicates that it is critical to increase the values of the meteorological parameter. For example, in the dynamics of the minimum air temperature, the third member of the model in Table 5 is a crisis for increasing this factor over time.

The first term of the model (2) of the trend is the modified law of Laplace (in mathematics), Mandelbrot (in physics), Tsipf-Pearl (in biology) and Pareto (in econometrics). It shows an exponential decrease (for maximum and average annual temperature) or increase (for minimum air temperature) over time.

As a rule, the first member of the model is a natural component, and the second and subsequent members of the model show biotechnical, in particular anthropogenic, influence. Then it turns out that the second term according to the exponential growth law gives a dynamic growth of the maximum and average air temperature. Apparently, the second term of the trend shows anthropogenic influence.

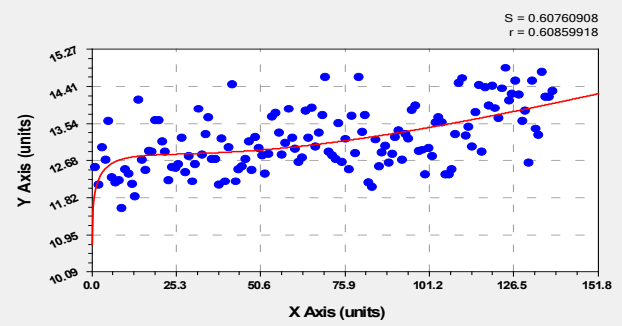
The third-fifth members have the amplitude of the oscillation according to the law of exponential growth or death (Laplace's law according to the exponential law of growth in the second member of the minimum temperature). Sevilleta are infinite-dimensional, because due to the law of Laplace, the change of the amplitude shows the continuation values to 1879 and after 2017.

7. Graphs of Air Temperature Dynamics

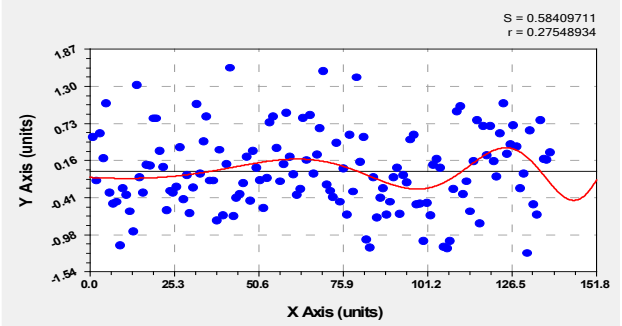
7.1 Maximum Air Temperature Dynamics

The adequacy of the model (1) according to Table 5 is equal to the correlation coefficient 0.7011 (Figure 1).

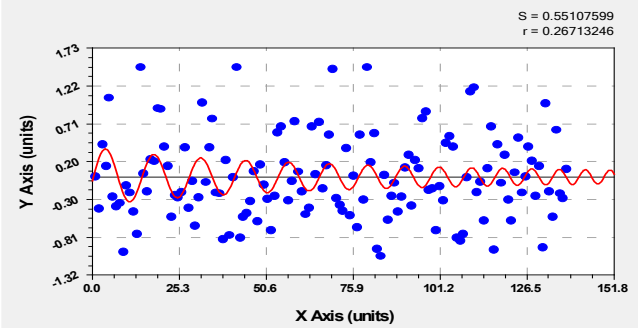
Trend contains two members (Figure 1) and obtained a correlation coefficient of 0.6086. Moreover, the pattern is clearly nonlinear, so we consider attempts to apply linear models in climatology to be an obvious simplification. Although the linear equation has a correlation coefficient of 0.5610, however, in the identification method [5] we use the linear model only at the beginning of the modeling process. The reason for the "love" of scientists to approximate linear trends lies in only one thing – linear models are universal to the positive and negative halves of the abscissa. Therefore, linear models are valid only on short dynamic series, and on long ones, as in this example in 139 years, linear trends are very rough, and primitive.



Two-term trend



First oscillation



The second oscillation

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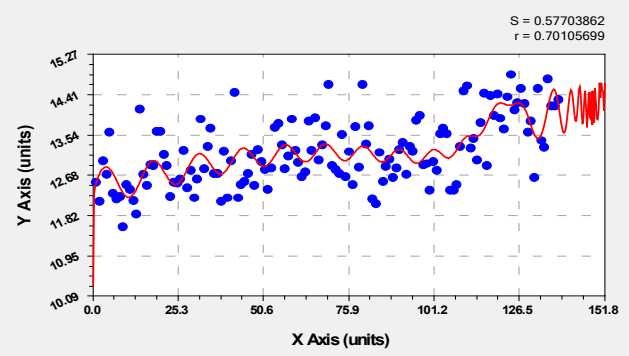


The residues of the model from Table 5

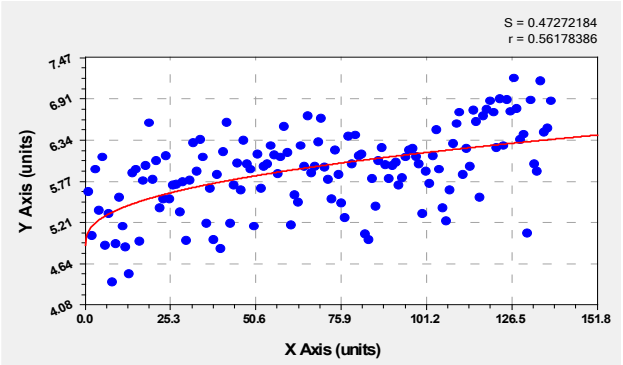
Figure 1. Graphs of four members of the model (1) maximum temperature dynamics: S-dispersion; r-correlation coefficient

The first wavelet as the third term of the general model (1) (Figure 1) with a correlation coefficient of 0.2755 after the Union changed sign in amplitude and became the law of exponential death. This led to tremor (shaking after 2017). The second wavelet with the adequacy of 0.2671 has not changed in design. As can be seen from the general schedule for the four members, after 2017 there is a tremor (jitter) due to a significant decrease in the half-period of oscillations.

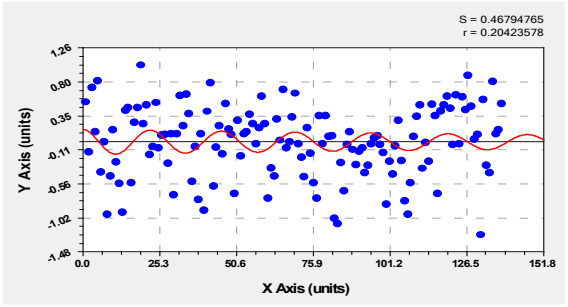
7.2 Minimum Air Temperature Dynamics

The first wavelet shows a slow decrease in the amplitude of the oscillation according to Laplace's law of exponential death, with the half-period of the oscillation growing from 10.59745 years (approximately equal to the solar activity cycle on average 11.3 years) in 1879. The hesitation calms down and is not dangerous for the future.

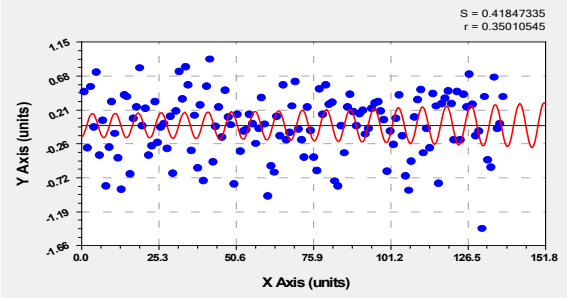
Due to the negative sign of the second wavelet tries to reduce with increasing amplitude by the law of exponential growth tendency to increase the minimum temperature. When this wave increases the period of oscillation and also calms down.



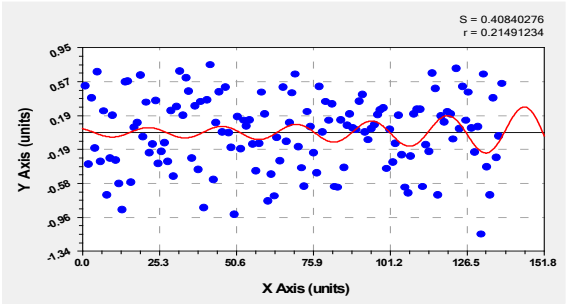
Single-member trend



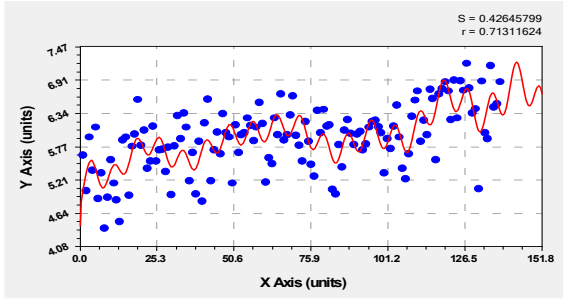
First oscillation



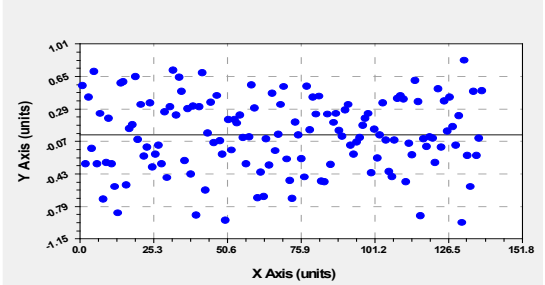
The second oscillation



Third oscillation



One member of the trend and three variations



After the remains of four members

Figure 2. Graphs of the General model (1) minimum air temperature dynamics

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The third wavelet increases the amplitude according to the law of exponential growth and also with an increase in the half-period from 11.63078 (approximately the cycle of solar activity) in 1879, that is, this wave also calms down. This fact means only one thing: the greatest danger to climate change is the dynamics of the maximum temperature with chaotic changes in the future.

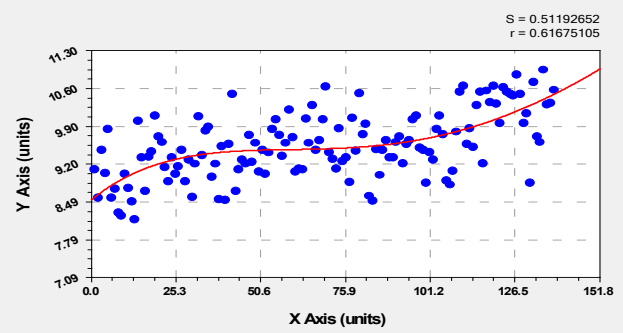
As can be seen from the general graph for the four members, after 2017 there is also a small tremor (shaking), but it is smaller compared to the maximum temperature. It turned out that this jitter will be changed by other wavelets. For the residues shown in figure 2 by the points at the end, another 60 components were obtained by the formula (1). The stop of the simulation was performed after reaching the residuals (absolute simulation error) of the measurement error at the end of the 19th century at ±0.05˚C.

Other vibrational perturbations can be identified from the residuals, but the correlation coefficients will be much less than 0.1.

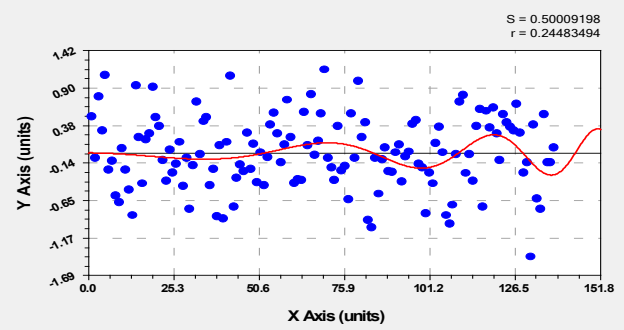
7.3 Dynamics of Average Annual Air Temperature

With a correlation coefficient of 0.7086, a four-membered model with strong coupling adequacy was obtained (Figure 3) for a number since 1879. And for the series from 1659 0.5893 was obtained, that is, with an average level of adequacy with a correlation coefficient from 0.5 to 0.7. It follows that increasing the length of the dynamic series in retrospect reduces the adequacy of the simulation.

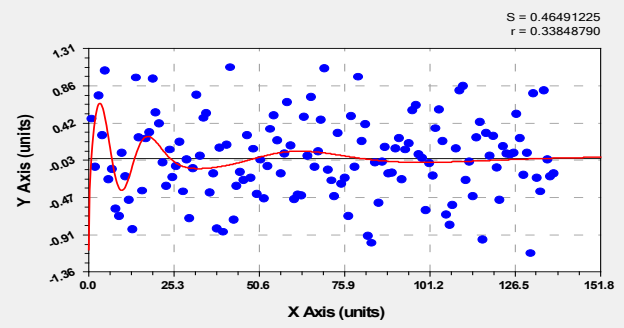
The trend contains two members and has a correlation coefficient of 0.6168, which is greater than 0.5618 for the single-term trend of the minimum temperature and 0.6086 for the two-term trend of the maximum temperature. The intensity of the exponential growth of the average temperature equals 1.03071 that more than 1. Therefore, for the second term, the increase in the average temperature of Central England is accelerated. In comparison with the maximum temperature, the intensity of the exponential growth is 1.03071 / 0.39342 = 2.62 times more.



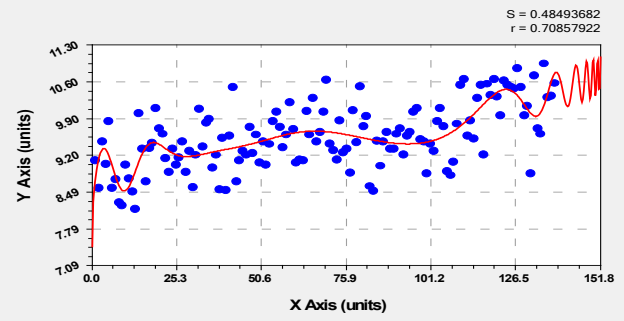
Two-term trend



First oscillation



The second oscillation



Two members of the trend and two wavelet

Figure 3. Graphs of the General model (1) dynamics of average annual temperature

Because of the negative sign, the first wavelet is focused on reducing the average annual temperature. At the same time, this desire increases in amplitude, but increases in frequency of oscillation in 1879, the period of oscillation was 2 55.65055 111.3 years. This period is almost 10 times the cycle of solar activity or 5 times the cycle of the sun's core around itself. Similarly, the second wavelet in 1879 had a period of oscillation of 2 5.96040 11.92 years, that is, equal to the cycle of solar activity.

Then it can be concluded that until the end of the XIX century, the climate was more clearly subject to the cycles of solar activity, but then humanity introduced chaotic changes in the vibrational adaptation of climate and weather.

The graph of the four-membered model in Figure 3 shows that after 2018, the average temperature, as well as the maximum air temperature, receives a tremor or jitter with an in-

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creasing frequency of oscillation as a result, the climate as it goes to the dressing, as it happens before the car accident.

8. Binary Relations between Different Temperatures

Binary relations, and without any pre - conditions of selection, are necessary to assess the level of adequacy of mutual relations between the accepted factors. Due to the quantum entanglement of the relations between the factors, the wave equations for (1) are not obtained, so only the trend model (2) was adopted for identification. Then the correlation coefficient shows quantum certainty, and the difference 1 — r gives quantum entanglement.

8.1 Effect of Maximum Air Temperature

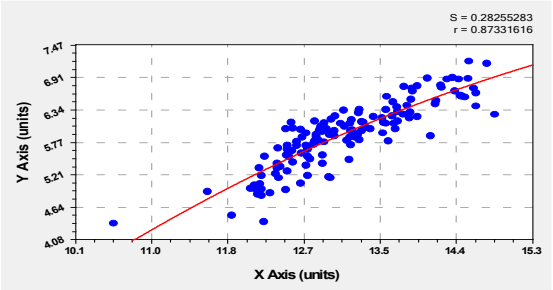
The other two factors are affected by this air parameter according to the two-term trend formulas (Figure 4):

- the effect of the maximum temperature on the minimum temperature with a correlation coefficient 0.8733 trend (2) as an equation

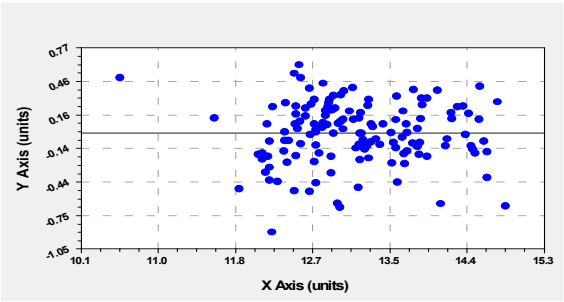
$$t_{min} = -11.36693\exp(-0.054204 t_{max}^{1.14678}) + 0.93529 t_{max}^{1.16677}\exp(-0.027815 t_{max}^{1.21768}) \quad (3)$$

- the effect of the maximum temperature on the average temperature at a correlation coefficient of 0.9760 according to the formula

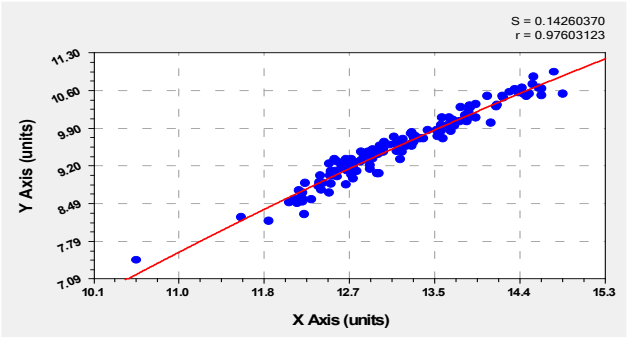
$$\bar{t} = -5.43734\exp(-0.050581 t_{max}^{1.07379}) + 0.98493 t_{max}^{1.07640}\exp(-0.011358 t_{max}^{1.23682}) \quad (4)$$



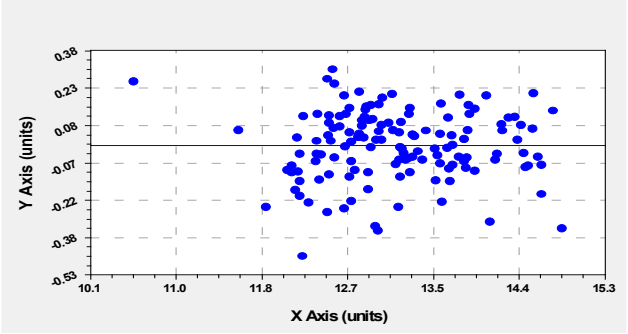
At minimum temperature0.8733



After the remains of two members of the trend (3)



Average temperature 0.9760



After the remains of two members of the trend (4)

Figure 4. Effect of maximum air temperature on other parameters: left column-trend charts; right column-trend balances

As the maximum temperature increases, both other temperatures begin to rise with negative values of -11.37 ^{0}C for the minimum temperature and -5.44 ^{0}C for the average temperature. In this case, the second member receives a complete construction of the biotechnical law [5]. From the residues in Figure 4 it can be seen that their location relative to the axis of the abscissa is not visible patterns.

8.2 Effect of Minimum Air Temperature

Figure 5 shows graphs of the effect on other parameters.

Graphs of the left column with quantum certainty (disarray) are characterized by equations:

- the effect of the minimum temperature on the maximum temperature at a correlation coefficient of 0.8761 according to the formula

$$t_{max} = 7.99814\exp(-0.028312 t_{min}^{2.16364}) + 1.31757 t_{min}^{1.19252} \quad (5)$$

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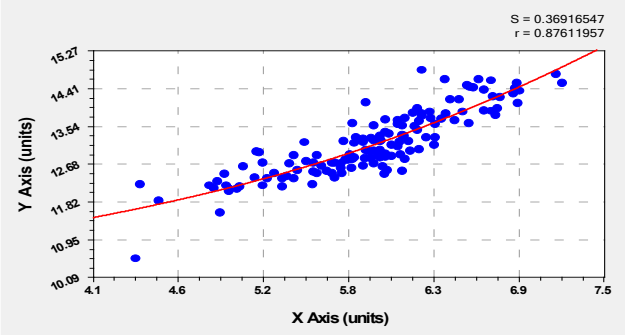
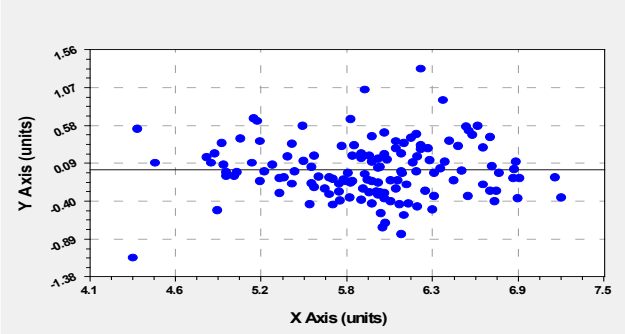
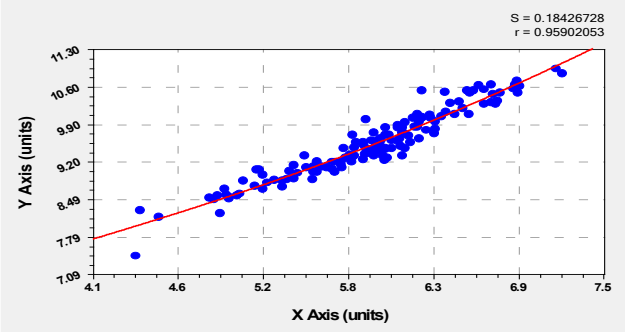


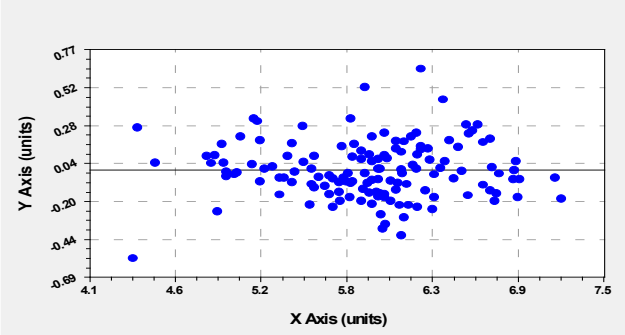
At maximum temperature 0.8761



After the remains of two members of the trend (6)



Average temperature 0.9590



After the remains of two members of the trend (7)

Figure 5. Effect of minimum air temperature on other parameters: left column-trend charts; right column-trend balances

- the effect of the minimum temperature on the average temperature with a correlation coefficient of 0.9590 in the expression

$$\bar{t} = 3.90185\exp(-0.026934 t_{\min}^{2.20399}) + 1.17222 t_{\min}^{1.11458} \quad (6)$$

With increasing minimum temperature on the first member, other types of temperature decreases, but on the second member in the form of a demonstration of the law grow with intensity 1.19252 and 1.11458. Quantum entanglement of residues is heterogeneous: in the middle of the minimum temperature there is a crowding of points.

8.3 Effect of Average Air Temperature

This effect is shown by the graphs in Figure 6, which have been identified by equations of the form:

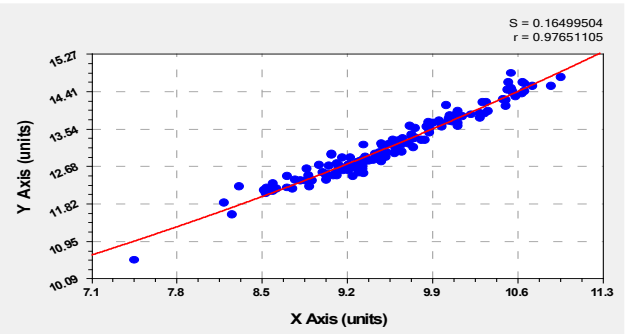
- the effect of the average temperature on the maximum temperature at a correlation coefficient of 0.9765 for the formula

$$t_{\max} = 4.16442\exp(-0.0069492\bar{t}^{2.44380}) + 0.94934\bar{t}^{1.13900} \quad (7)$$

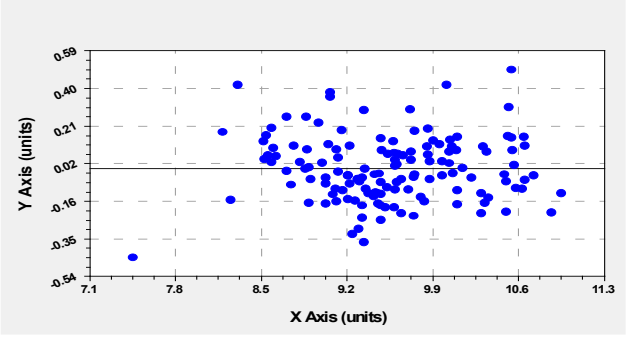
- the effect of the average temperature minimum temperature with coefficient of correlation 0.9592 by the formula

$$t_{\min} = -3.73112\exp(0.071287\bar{t}^{1.15935}) + 0.88263\bar{t}^{1.31899}\exp(-0.0065474\bar{t}^{1.15314}) \quad (8)$$

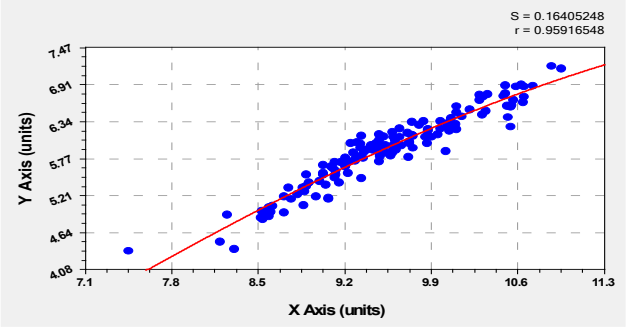
The comparison shows that the greatest influence with the correlation coefficient 0.9765 is exerted by the average temperature on the maximum air temperature in the surface layer of the atmosphere. At the same time, all six equations refer to strong connections, so there is a high quantum certainty between the three types of temperature. But when predicting the greatest heuristic (meaningful) essence showed the maximum temperature.



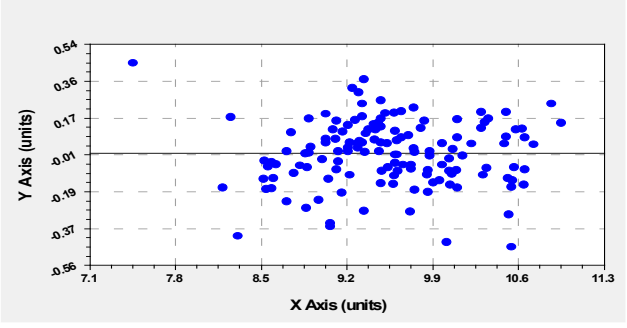
At maximum temperature 0.9765



After the remains of two members of the trend (9)



At minimum temperature 0.9592



After the remains of two members of the trend (10)

Figure 6. Influence of average air temperature on other parameters: left column-trend charts; right column-trend balances

At zero values of the influencing variables according to the previous formulas, we obtain the limit theoretical values of the dependent indicators (Table 6).

Table 6. Limit values of meteorological parameters at zero values of influencing variables by equations (3-8)

Influencing factors (characteristic *x*)	Dependent factors (indicators *y*)		
	t_{max}, °C	t_{min}, °C	$\bar{t}$, °C
Maximum temperature t_{max}, °C	-	-11.37	-5.44
Minimum temperature t_{min}, °C	8.00	-	3.90
Annual mean temperature $\bar{t}$, °C	4.16	-3.73	-

From the data of the Table 6 it is seen that the most dangerous is the change in the maximum temperature, when at zero maximum temperature the minimum temperature in the year reaches -11.37 ^{0}C.

Figure 4 shows that the minimum temperature was always positive and its lowest value was 4.36 ^{0}C in 1879. In the same year, the maximum temperature also had a minimum value of 10.52 ^{0}C. In the future, both of these indicators only increased, respectively, to 6.87 and 14.30 ^{0}C in 2017. Then lowering the maximum temperature to 0 ^{0}C becomes a climatic disaster.

9. Quantum Entanglement between Temperatures

In Figure 5-8, quantum entanglement is characterized by residues in the second column of the graphs. The correlation coefficient of quantum entanglement is determined by the expression (Table 7).

Table 7. Values of correlation coefficients by equations (3-8)

Influencing factors (characteristic *x*)	Dependent factors (indicators *y*)	Correlation coefficient quantum behavior	
		unraveling	entanglement
Maximum temperature t_{max}, °C	t_{min}, °C	0.8733	0.1267
	$\bar{t}$, °C	0.9760	0.0240
Minimum temperature t_{min}, °C	t_{max}, °C	0.8761	0.1239
	$\bar{t}$, °C	0.9590	0.0410
Annual mean temperature $\bar{t}$, °C	t_{max}, °C	0.9765	0.0235
	t_{min}, °C	0.9592	0.0408

We introduce a new concept – *quantum unraveling*, which shows the adequacy of the identification of mathematical regularities in the form of wavelet signals. Therefore, the adequacy of *quantum unraveling* is characterized by the same value of the correlation coefficient, which was obtained during the application of the method of identification of asymmetric wavelets.

As can be seen from Table 7, the quantum entanglement of three meteorological parameters is very small.

In the simplest case, the sides along the abscissa and ordinate axes of the rectangle describing the swarm of points (up to 3300 points the software environment can show the entire swarm) become the boundaries of the residues on the graphs in Figure 4-6.

Coordinates of the centers of the remnants of the swarm can be adopted an arithmetic average of the values on the abscissa and the ordinate. There may be special centers for fashion and other statistical indicators of the sample.

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10. Conclusions

For each ground-based weather station, it is necessary to study *the point distributions* of meteorological measurements. Pair connections between meteorological parameters allow studying the *quanta of climate* and weather behavior for different time periods: long-term, annual, plant ontogenesis period [8-11], seasonal, monthly, weekly, daily, hour and minute.

Then we distinguish two types of quanta of behavior:

First, in dynamics, each factor is divided into the sum of wavelets, that is, in time, the factor is represented as a bundle of solitary waves (solitons) and this process is characterized as *quantum unraveling*;

Secondly, the mutual influence of the above three factors with uniform or uneven periodicity of measurements additionally obtains *quantum entanglement* in some boundaries.

Thus, any phenomenon or process can be estimated by the level of adequacy (correlation coefficient) of decomposition of the functional connectivity of the system behavior into *quantum unraveling* and quantum entanglement.

The concept of vibrational adaptation in nature suggests that between the selected factors in Table 1. There are dependencies in the form of wave equations. However, it turned out that there is no wave connection between these three temperature factors, which indicates the presence of a sufficiently strong quantum entanglement of meteorological data.

If the remains after the wavelet analysis are not further modeled, then experts say about some noise. But we believe that noise can only be called residues that are equal to or less than the measurement error. Therefore, part of the noise exceeding the measurement error should be attributed to quantum entanglement. And the share of parameter values determined by the revealed regularities should be attributed to *quantum unraveling*.

The coefficient of correlation variation, that is, a measure of the functional relationship between the parameters of the system (annual weather at the weather station), is equal to $7.4073 / 3^2 = 0.8230$. As the influencing variable at the first place was the meteorological parameter «Annual mean temperature», the second «Maximum temperature» and in third place – «Minimum temperature». As the dependent measure in these areas there are three kinds of temperature.

The comparison shows that among the binary relations between the three temperatures, the greatest influence with the correlation coefficient 0.9765 is exerted by the average temperature on the maximum air temperature in the surface layer of the atmosphere. At the same time, all six equations refer to strong connections, so there is a high quantum certainty between the three types of temperature. But when predicting the greatest heuristic (meaningful) essence showed the maximum temperature.

The hierarchy of statistical climatology methods based on the identification of stable laws and regularities is as follows: 1) formation of tabular model and cluster analysis of factors; 2) rating of objects and subjects in a given system of factors; 3) ranking distributions or wavelet-analysis of dynamics of factors; 4) analysis of the vibrational adaptation of the system parameters; 5) factor analysis of the performance of the system; 6) the rating of the influencing and dependent factors; 7) analysis of binary relations between factors; 8) fractal analysis of wavelets; 9) preparation of predictive models for dynamics wavelets; 10) multivariate hierarchical modeling.

Methods 3-7 have been shown in this article.

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ARTICLE

Wolf is Coming—Dynamic Classification Prediction Model of Vespa Mandarinia

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ABSTRACT

Given the threat of Vespa mandarinia invasion to ecological balance, according to the data and information provided, the dynamic reproduction model of Vespa mandarinia is established by using natural domain interpolation, and the variation law of total bumblebee with time, latitude, and longitude is obtained. At the same time, we established the classification prediction model by using a neural network and established the mapping relationship between time and space to evaluation grade.

We meshed the area provided by the title, assigned values to the location of Vespa mandarinia (VM), and established a VM diffusion model with natural neighborhood interpolation. Its propagation process is simulated by cellular automata. It is determined that VM spreads in a circular shape centered at (122.93174°W, 48.93457°N) and (122.57376°W, 49.07848°N) in the Washington area, with the farthest distance being 1184.4 km and 985 km respectively.

We set up a classification prediction model for better classification. According to the image upload time and location, SVM and neural network are used for classification prediction, and the classification accuracy is 74.26% and 97.60%, respectively, and the neural network has higher classification accuracy. So we choose the neural network.

1. Introduction

The invasion of alien organisms has had a huge impact on local agriculture, food production, and species diversity. Recently, the VM was discovered in Vancouver and the neighboring Washington State area. The discovery of this invader has sounded a wake-up call for the locals. The frightening thing is that this insect is the largest known wasp in the world [1]. The accidental introduction of the VM has brought serious consequences to European honeybees. While attacking the hive and preying on European honeybees, it also affected its foraging activities and living space. At the same time, they are voracious predators of other insects that are considered agricultural pests.

In addition to the threat to the beekeeping industry, the invasion of Vespa mandarinia in North America is also concerning for public health [2]. Their poisonous needles

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sting people and can cause severe allergic reactions and even death. Therefore, this caused greater anxiety among the locals, and Washington State has set up a help phone and web-site for this purpose to count the wasps. However, there are several other VM that may be confused for them. Because bumblebees spread quickly and become pests, it is necessary to reliably estimate the potential range of bumblebees in North America to assess the possible impact on humans and guide future efforts to eliminate bumblebees [3].

2. The Establishment of Dynamic Propagation Model

Based on problems and data analysis results, we summarize the requirements to be considered in the VM propagation prediction model:

(1) The model can reflect the interaction between virtual machine propagation and diffusion in various regions.

(2) This model can reflect the influence of the historical development of the various regions on their future.

(3) The model must be able to simulate the change of virtual machines in all regions.

Based on the above conditions, we chose the cellular automata model. Cellular automata, proposed by Stanislaw Ulam and John Von Neumann of Alamos National Laboratory, New Mexico, USA, is a dynamic system based on time-space dispersion, which is widely used to analyze diffusion and propagation problems [4]. A cellular automaton is represented by a regular grid, each grid represents a unit, and the state of each unit is finite (open or closed). The cells around a cell are called neighbors. After the initial state is set at time t = 0, the next time t+1 will produce a new generation of cells. The status of the new unit is determined by the common status of itself and its neighbors at the previous moment, and so on, until the status of each unit is updated. The cells in the system are scattered in the grid, and the changes of neighbors are influenced by local evolutionary rules. Finally, under the accumulation of time and iteration of space, it spreads to all parts of the system to realize the change of the whole state [5].

2.1 Cellular Automata Model

The definition of two-dimensional cellular automata is as follows:

$$C=(D_2,S,N,f) \tag{1}$$

D_2 represents a two-dimensional Euclidean space, S is the cell state set, N is the cell neighborhood, F is the cell state transformation rule.

For the unit located in the R unit, its state at that time is expressed as :

$$S(r,t)=\{S_1(r,t),S_2(r,t),...,S_k(r,t)\} \tag{2}$$

In which k States of the cell located in the r lattice at time t are shown. The corresponding States in the VM prediction model can be divided into the area where there is no VM nesting, that is, Clean Land (CL); There is an area where VM nests and no measures are taken to clean it up at time t, that is, Invaded Land (IL); There is an area where VM's nest and measures are being taken to clean it at t moment, that is, Land Being Cleared (BL); And the land of hibernation (HB), where wolves are hibernating.

N_q is the q's neighbor of the cell located at r.

$$N=\{N_1,N_2,...,N_q\} \tag{3}$$

According to the propagation mode of virtual state, the distance from a new queen to build a nest is estimated to be 30 km. 30 km is equivalent to three or four cells, so the grid with 7×7 neighbors is defined as shown in Figure 6.

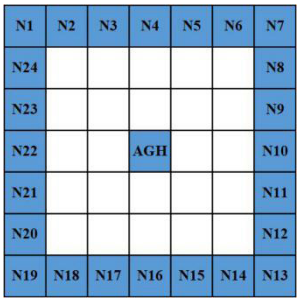

Figure 1. Cellular automata neighbor structure diagram

f is the transformation rule of the cellular state at position R from the time t to the time t+1. Where fi represents the ith transformation rule.

$$f=\{f_1,f_2,...,f_m\} \tag{4}$$

If the current state of a cell is, then the jth transformation rule of its state at time t+1 is

$$S(r,t+1)=f(S(r+N_1,t),S(r+N_2,t),...,S(r+N_q,t)) \quad j=1,2,...,m \tag{5}$$

First, randomly assign cells whose initial state is IL in a cell space of 530×1000, and the number is less than 0.02% of the total cell space. Secondly, the cell space is traversed. According to the change probability determined by Robinet et al [6]. The evolution rules in the determined

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topic are as follows:

Rule 1. If there are I cells in the states of IL and BL in the neighborhood of a cell in the state of CL, r will change to the state of IL with a certain probability (i×0.14).

Rule 2. At present, the cell in HB state will become IL state with a certain probability. (0.5).

Rule 3. At the present moment, the cell in the IL state will become a BL state with a certain probability. (0.3).

Rule 4. At the present moment, the cell in BL state will become CL state with a certain probability. (0.35).

Rule 5. All rules are executed at the same time.

2.2 CA Data Preparation

2.2.1 Spatial Data Interpolation

In the provided dataset attachment, there are 14 cases in which the wasp attribute is Positive ID in the report information, and each case report corresponds to different geographic information. It is very important to accurately interpolate the spatial attribute of its location (the probability of Asian giant bee VM invasion). From the spatial point of view, the more the locations tend to be the same, the more the probability of being invaded by VMs tend to be the same. The probability that two opposite points tends to separate is low [7].

The purpose of using spatial interpolation is to supplement the spatial data that can- not be measured in space. In this topic, for various reasons, it is impossible to obtain the distribution of all wasps by measurement. At this time, interpolation technology is needed to simulate and generate these data, to understand the distribution of spatial regions as a whole.

The positive markers, untreated markers, negative markers, and unverified markers in this topic were assigned respectively, and the results are as follows:

$$\begin{aligned} Z_{PositiveID} &= 100 \\ Z_{Unprocessed} &= 25 \\ Z_{NegativeID} &= 1 \\ Z_{Unverified} &= 25 \end{aligned} \tag{6}$$

2.2.2 Grid Processing

The whole continuous space needs to be analyzed, so we grid the spatial data to make the analysis result better. To show the distribution of spatial data directly from the interface when analyzing spatial data, we generate isolines by interpolation, so that we can directly see the invasion probability of VM to different geographic locations from the interface. Common meshing algorithms include rectangle meshing and triangle meshing. To make the algorithm simple and the program easy to implement, we use a rectangular grid and select natural neighbors to interpolate. The interpolation results are shown below.

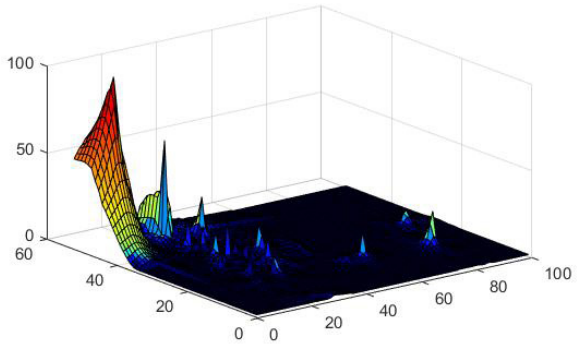


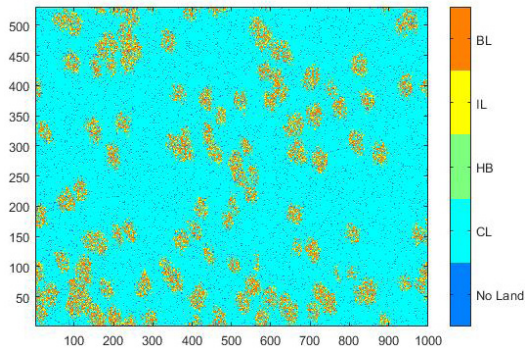
Figure 2. Probability spatial distribution of VM invasion

2.3 Analysis of Simulation Results

The results of the cellular automata simulation show that VM will spread around in an elliptical pattern with VM's current nest as the center, and the area of Clear Land will drop rapidly while the area of invaded land will increase in a blowout manner.

The predicted results showed that the growth rate of VM decreased after the 70th year, which might be caused by the following two factors: the population of VM increased sharply after the 70th year, the competition within the species of VM intensified, and the number of bees for the food of VM decreased;With increased government oversight, 60 percent of the VM nests found each year will be cleared. These factors resulted in a 17% decrease in VM transmission rate and a 29% decrease in population density [6].

Because VM generally does not nest 3 to 6 feet above the ground, it usually nests underground. Therefore, it is difficult to find the nest of virtual machines and clean it up. Only 30% 40% of VM nests are found to be cleared every year; meanwhile, the cleaned nest may be rebuilt by other virtual machines, which worries residents [6].



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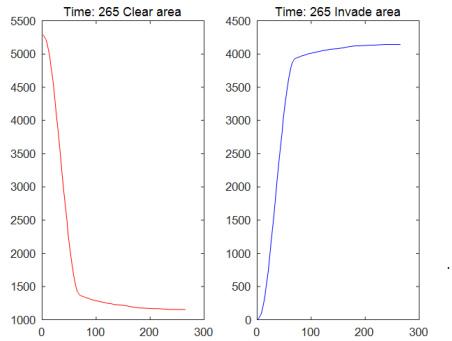

Figure 3. The transmission state of VM in 20 years and the number of CL cells and IL cells after 265 years

2.4 Washington Predicts Results

To avoid spatial autocorrelation caused by sampling deviation and over-fitting of specific areas, we take the reported geographical distance as the standard, refine the space based on distance sparsity, and exclude another event whose reported position is less than 5 km [8].

The prediction result is as follows, taking the geographic location of the sparse positive ID as the initial value.

As shown in Figure 4, influenced by the topography of the Washington area, it is concluded that the nesting range of VM will be covered by ellipse centered on (122.93174°W,48.93457°N) after 20 years, and the farthest distance is 1184.4 km; The ellipse is centered at(122.57376°W,49.07848°N), covering 985 kilometers.

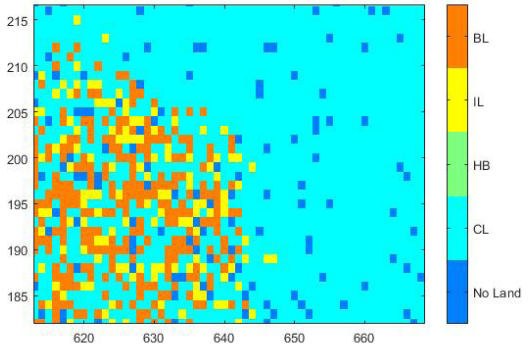

Figure 4. Propagation pattern of a single VM nest

Table 1. Positive ID Sparse Results

Latitude	Longitude
48.77753	-123.94313
48.92751	-122.81065
48.95558	-122.74501
48.97194	-122.70224
48.98099	-122.70094
48.99389	-122.68850
49.02583	-122.66103
49.06021	-122.64164
49.14939	-122.41861

2.5 Forecast the Resulting Hit Rate

According to the mode of transmission of VM, the nesting distance of new bees is estimated to be 30 kilometers. Taking 30 km as the standard, the spatial hit rate is defined as the ratio of the actual distance of each neighbor to 30 km in N_i (i = 1, 2, . . . , 24).

$$Hit_i = \frac{S_{Ni}}{30} \tag{7}$$

Determine the average hit rate:

$$Average\ Hit = \sum_{i}^{24} Hit_i/24 \tag{8}$$

As shown in Table 2, Average Hit = 1.0012, and the closer the hit rate is to 1, the higher the accuracy of predicting VM spatial propagation by the model.

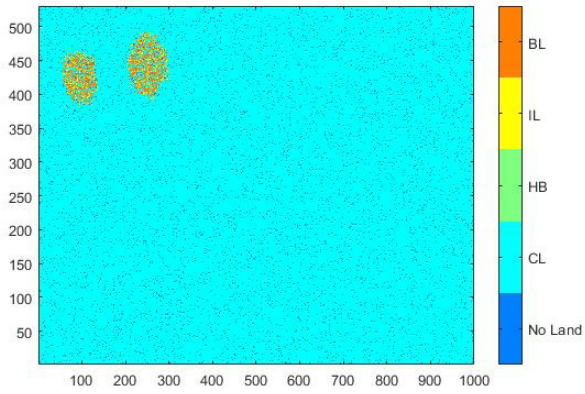

Figure 5. Forecast results of VM communication in Washington

Table 2. Space hit rate

Neighbour	N_1	N_2	N_3	N_4	N_5	N_6
Hit Rater	1.226575	1.042388	0.914235	0.867320	0.914235	1.042388
Neighbour	N_7	N_8	N_9	N_{10}	N_{11}	N_{12}
Hit Rater	1.226575	1.042388	0.914235	0.867320	0.914235	1.042388
Neighbour	N_{13}	N_{14}	N_{15}	N_{16}	N_{17}	N_{18}
Hit Rater	1.226575	1.042388	0.914235	0.867320	0.914235	1.042388
Neighbour	N_{19}	N_{20}	N_{21}	N_{22}	N_{23}	N_{24}
Hit Rater	1.226575	1.042388	0.914235	0.867320	0.914235	1.042388

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3. The Establishment of Classification Prediction Model

Analyze the information provided on the topic based on time and space dimensions. To reduce the error rate of classification results, we try to establish a spatiotemporal comprehensive evaluation model with SVM and neural networks.

3.1 Support Vector Machine

Support Vector Machine was first proposed by Cortes and Vapnik in 1995, and it is widely used in linear and nonlinear classification. It shows advantages in solving the problems of a small sample, nonlinearity, and high-dimensional pattern recognition. Here, we set up an SVM data network [9]. The classification is based on the longitude and latitude of reporting points and discovery time of reporters, and the classification result is Lab Status.

3.1.1 Processing Flow

Different dimensions of data have different dimensions. To prevent the difference in the order of magnitude between input and output data, the original data is normalized first.

$$x^* = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{9}$$

Traditional SVM is only used as a linear classifier, while virtual machine classification is complicated, so it can't be classified visually by one line and one side. Here's a brief introduction to the kernel function.

General conditions are:

$$k(x,y) = < f(x), f(y) > \tag{10}$$

<x,y> is the inner product of x and y. Using kernel function, the original space (Euclidean space Rn) is mapped to the new space (Hilbert space H), so that the hypersurface model of the original space corresponds to the hyperplane of feature space, thus completing the corresponding classification task [10]. Select linear kernel as kernel function and its inner product function is as follows.

$$k(x,y) = x^t y \tag{11}$$

After introducing the corresponding kernel function, the test set data can be used for classification training, and the trained SVM network can be used for classification testing of the original data.

3.1.2 The Classification Results

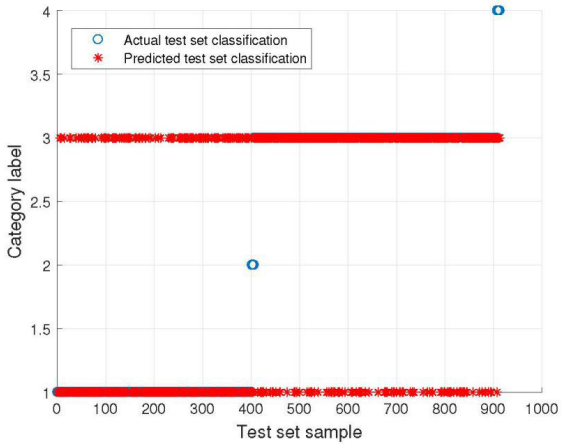

Figure 6. Actual & Predicted classification diagrams of the test set

As shown in Figure 6, witness reports are divided into four categories, represented by the numbers 4, 3, 2 and 1 respectively, corresponding to positive ID, negative ID, unprocessed and unverified respectively. Because the positive ID and unprocessed contain too little data, it is compressed to a single point in the figure, and most of the samples are negative and unverified.

To illustrate the classification accuracy, a new hit rate function, accuracy, is introduced. Accuracy is the proportion of correctly predicted classification result P_i to the actual category A_i.

$$Accuracy = \frac{P_i}{A_i} \tag{12}$$

The accuracy of classification is 74.2607%, which is low because there are too many differences in the number of samples.

3.2 Neural Pattern Recognition

The neural network is a mathematical model or computational model which simulates the mechanism and function [11] of the biological neural network and is used to estimate or approximate the function. It has been widely used. The neural network is applied to pattern recognition by using its adaptive characteristics [12]. The input variables are latitude, longitude and time reported, and the output variables are Lab Status.

3.2.1 Parameters Show

To make the model better predict the corresponding classification results, we selected 15 neurons in the hidden

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layer and 4 nodes in the output layer and the training function used is (training by using scaled conjugate gradient backpropagation).70% of the data are selected for training, 10% for verification and 20% for testing. The model is structured as follows.

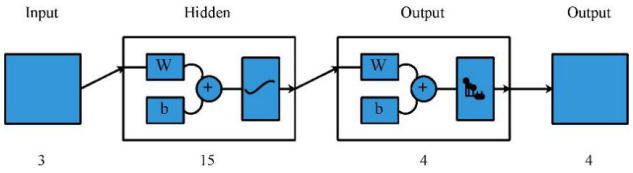

Figure 7. Schematic diagram of the model

After training, build the corresponding neural network relationship. See the following training rendering.

It can be seen from the below training curve that with the increase of training times, the error is decreasing. After 249 training times, the error has converged to the required precision and reached the global optimum.

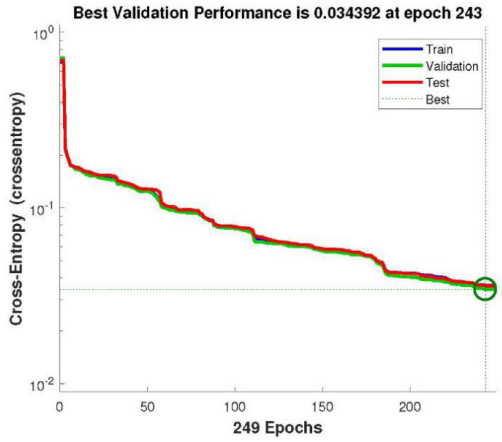

Figure 8. Training Curve

3.2.2 The Classification Results

After completing the training, the students enter the original data to obtain the original classification and prediction classification as shown in the following figure.

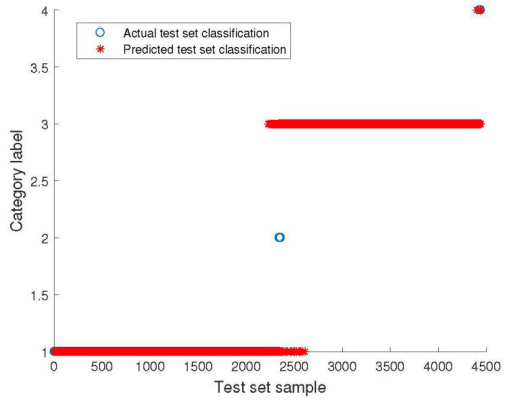

Figure 9. Neural network classification results

Eyewitness reports are also divided into four categories, and the classification is the same as the pictures. After calculation, the accuracy of the neural network is 97.6%. As can be seen from Figure 9, most of the eyewitness reports were correctly classified. The classification accuracy of the neural network is higher than that of SVM, and the normal distribution also has corresponding classification results, which shows a better prediction effect.

3.3 Results Analysis

After comparison of SVM classification and neural network classification, it is known that neural network has a better effect in classification prediction. Therefore, we choose to use a neural network to build the space-time comprehensive evaluation model. Input VM's location of the latitude and longitude, time, after the trained neural network, can get the accuracy of more than 97.6% of the classification results, if the positive ID, then need to send more staff to carry out field investigation.

4. Conclusions

According to the Vespa mandarinia invasion in Washington State, we established a diffusion model by using cellular automata. After the simulation and modeling, the results show that after 70 years, the growth speed of virtual machines slows down, resulting in a 17% drop in the propagation speed of virtual machines and a 29% drop in population density. In order to make better spatio-temporal prediction, we used support vector machine and neural network to establish mapping relationship between the location and time of the witness and the local wasp situation, and then establish network mapping for classification verification. The results show that neural network is superior to the support vector machine in classification prediction.

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ARTICLE

Flower Farms Environmental Performance Evaluation in Ethiopia

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ABSTRACT

Cultivation of cut flowers is a new agricultural sector in Ethiopia, which currently generates a high amount of income for the country's developments. Despite its significant contribution to economic developments; many issues were raised from communities and environmentalists concerning its environmental performance. Based on this issue the study assesses cradle to gate of cut flower production in the Wolmera district. The main objective of the study was environmental performance evaluation of flower farms in Wolmera district, Oromia regional state, Ethiopia related to operational activities throughout entire life cycles of cut flower production. In this study, primary and secondary data were collected using ISO 14031 standard structured with LCA tool methodology. Data were collected by inventory using an on-site data collection system from its sources. Based on data collected GHG (CO_2, N_2O, CH_4 & NH_3) emissions to the atmosphere were evaluated by using an inter-governmental panel on climatic changes (IPCC 2006) for inventory data and eutrophication & acidification estimated from data tested at laboratory levels. Similarly, the study also assesses banned chemicals used in the farms through inventory data assessment, and about 156 chemicals applied in the farms were collected to screen out those banned chemicals used and the two most extremely hazardous chemicals (Impulse & Meltatix) banned by WHO identified in the study. As it understood from a general assessment of all flower farms; all of them haven't EIA document established before construction in the district and production started with having less attention for EHPEA code of conducts in the flower farms which faces the environments for high impacts by emission emitted from flower farms in the district as a whole.

1. Introduction

Ethiopia is the second-most populous country in Sub-Saharan Africa and with a current population growth rate of 2.6%, it made one of the highest populous country in the world [1,2]. As the population growth continues the pressure on existing natural resources and ecosystems increases within time proportionally. Most Ethiopian people depend on consumable and non-renewable resources to obtain the necessities of life; with this rate of population growth can lose the abilities of sustainable life for societies. Even today, evidence of deforestation and desertification, loss of biodiversity, land degradation is the most

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problem in the country [3]. Depletion of potable water and aquatic resources is continuous for agriculture without any recognition for the environmental issues [4]. In Ethiopia, most of the time agricultural productions are based on subsistence food crops production and coffee harvesting for exporting purposes dominantly, but recently agriculture sectors in the country moving from subsistence farming to commercial production which included flower farming for exporting purpose, especially in the central parts of the country which included Wolmera, Sululta, Ziway, Sebeta and others [5]. Among these, the Wolmera district is one of the areas found in the central parts of the country or district which is densely occupied by flower farms. Wolmera district is almost covered by high lands (>1100m a.s.l) that are most preferable for cut flowers or roses cultivation [6-8]. Therefore, this situation makes odd the areas to attract the investors than elsewhere, especially flower farm investors are attracted by this area. Unfortunately, at this moment only about twenty-one flower farms are on the function and the rests are already phased out.

Floriculture can be defined as "a discipline of horticulture concerned with the cultivation of flowering and ornamental plants for gardens and floristry, comprising the floral industry". It can also be defined as The segment of horticulture concerned with commercial production, marketing, and sale of bedding plants, cut flowers, potted flowering plants, foliage plants, flower arrangements, and noncommercial home gardening [9]. The Ethiopian floriculture industry started around 1980 when state farms began to export cut flowers to Europe and within a short period recognized as an international cut flowers business player next to Kenya in Africa. Because, Ethiopia has geographical advantages for floriculture industry developments; i.e. cut flowers grow well at high altitude or above 1100m [10]. As stated by Ethiopia's agroecology facilitate opportunities to produce different varieties of flowers in different ecological zones that used to increase flower industries through time in the country [11]. Cut flower includes all commercially cultivated rose and ornamental plants in the greenhouse or the field, especially in a controlled environment [12]. But, various cut flowers sometimes grow out of the greenhouse in many climatic conditions. The rapid growth of flower farms in Ethiopia in general, due to comfortable climatic conditions and natural resources, excellent governmental supports, good transportation system, and availability of abundant and cheap labor forces. Floriculture is used for luxury with high social value and rarely used for food. The demand for luxury is increased in the international market from time to time recently. The flower farms/industries are one part of the agricultural sectors in Africa just like other continents for economic developments at this moment [13-15].

The objective of this study is the environmental performance evaluation of operating systems within flower farms in Wolmera district, Oromia regional state, Ethiopia. The studied dedicated on water consumption and discharge, solid waste generation and discharge and energy consumption and emission during the flower plantation.

2. Methodology

2.1 Study Methodology

Study methodology is mainly based on selecting LCA tools for assessments and the main purpose of this selection tool study is to express the values of environmental management tools for a realistic case and to analyze. The result generated or aspects of the firms. Production of flower farms in Wolmera district is blamed by a large amount of chemical fertilizer, pesticides, and resource use. These create great problems on the environment through emission, discharges, and disposal to the environment in the district. The reason is to identify the environmental impacts or burdens within the sectors. It is vital to collect the necessary data from its sources. Based on this method to assess the issues in the current study it is best to choose a globally acceptable route (tool) to collect, organize, analyze and decide on the issues following new standard ISO 14031 & ISO 14044. Therefore, by using the new international organization for standard; the fundamental data were aggregated following the LCA method that passes at least four fundamental steps through product life cycles which included goal and scopes, data collection & interpretation [16]. It is easy to understand from schematic diagram overview steps that carried out for the implementation of environmental performance evaluation of cut-flower farms or industries within their operation, shown in Figure 1.

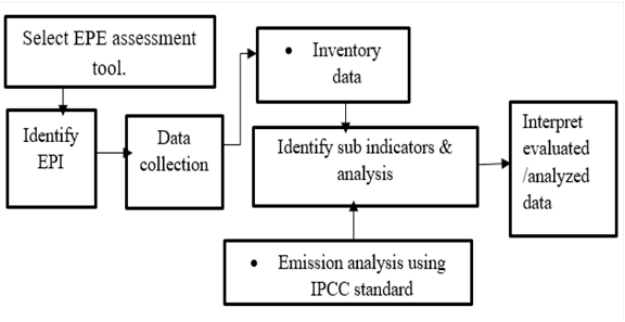

Figure 1. Study methodology schematic diagram.

The system boundary of study identification: The system boundary of any process describes the process's activity and input-output components, which have been engaged into account within a life cycle assessment [17]. For

this study, system boundary starts from land preparation to cut flower products transportation. The process included in the system was water consumption, energy consumption, chemical consumption, products, waste generates, and emission to the environments. Again, in this industry, some processes are excluded from the system boundaries of the current study which involves office activity, chemical container storage, and nursery site, shown in Figure 2.

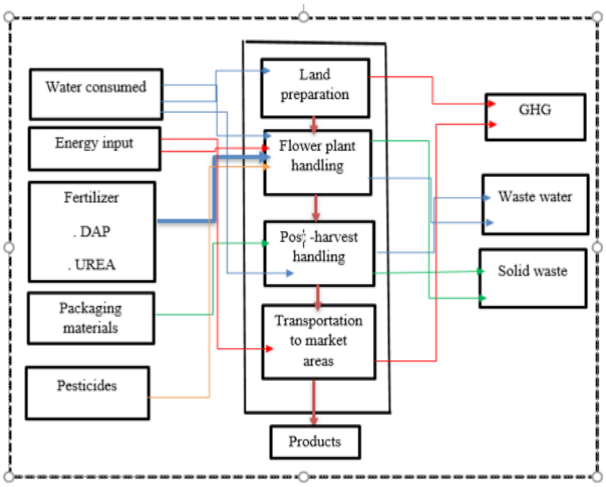

Figure 2. System boundary of the study

2.2 Core Indicators Selection for Study

Fundamental operational indicators are significant for an organization to establish a sustainable civilization and decreasing environmental burden (Jasch 2009). Also, sub-indicators use in combination with the core sets of indicators to measure and follow environmental performance for further accuracy. Indicators can direct types and amount of resources input and output easily to point out quantitatively the material utilized in an organization [18]. The most core indicators used or identified in this study were total energy used, the total amount of water used, total material input, total products, wastewater output, solid waste, and most known GHG as sub-indicators data were evaluated quantitatively using secondary and primary data collection system following ISO 14031 standard. All indicators identified were grouped under EPI which resulted in environmental condition indicators. But, most GHG emissions which included CH_4, CO_2, N_2O, NH_3, and eutrophication & acidification facilitators cannot be collected in the farm process as another type of parameter. Because of this, the amount of GHG, eutrophication & acidification emission from the farms was evaluated using different equations that measure emission emits from the agricultural process as per IPCC,2006, EPA (2003), and FAO from material inputs and outputs [19].

2.3 Inventory Data Collection

Inventory data collected from more than 21 flower farms existed in the district that have about 35 km distances from Finfinnee /Addis Ababa. The study covered more than one year time interval i.e. starting from February 2019 to April 2020. Collected data focused on four stages of cut flower harvesting activity that included land preparation stages which included the amount of energy used, amount of water used as inputs. The second data collection stage was from cut flower plant handlings, which focused on the amount of water, chemical, energy, material used, and products in the cut flower production farms. The third stage is from post-harvesting activities that involve data collection on water, chemical, cardboard paper used, and wasted materials throughout the activities and the fourth stages of flower production included transportation of product and data collection related to power consumption for transportation or fuel used [20]. Data collected at each stage of the flower harvesting activities were focused on selected indicators that are based on the input-output entire life cycle of the production. All necessary data were collected using both primary and secondary data sources by distributing questioner papers, reviewing related documents from various sources that included governmental offices, Private institutions, individual, nongovernmental organizations (NGO), interviewing the workers in floriculture industries, interview farm managers, direct physical site observation and assessing the existing situation of the study areas. All necessary data collected by using all mentioned data collection systems from cut flower farms and other data sources, but impossible to get data about GHG emission resulting from the materials used at four stages of cut flower productions. So, the emission of the firms quantified by using the amount of material used (fertilizer, chemical, fuel), amount of wastes burnt, amount of waste discharged/disposed of, and their emission factors with relating different study paper and IPCC 2006 guidelines for every emitted GHG from input-output indicators in data analysis [21].

2.4 Evaluate Potential Environmental Impacts

Data collected using inventory methods were evaluated and provide the necessary information, but impossible to get quantitative data about GHG emission from fertilizer and pesticides used in the farms, from residual biomass burnt in the farms, and from power energy (diesel fuel, petroleum fuel, and electricity) used for transportation of products and irrigation purpose in the farms. In the same way's eutrophication supporter discharged materials within the wastewater per hectare (NO_3, PO_4, NH_3, SO_4)

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require estimation. Therefore, it is obligatory to estimate the emission of material input-output in the flower farms and the most greenhouse gaseous emitted from the farms to environments (atmosphere) identified for estimation (CO_2, N_2O, and CH_4) and were evaluated or analyzed by using different equations which included equation for evaluation of GHG emitted from wastewater, from nitrogen synthetic fertilizer (DAP, UREA), from solid waste biomass burnt in the farms and combustion of energy sources by vehicles released to the environments at the end life cycle of cut flower production or transportation of main products evaluated using emission factors of the material used or disposed of; but the amount of eutrophication and acidification supporter materials calculated using laboratory results and wastewater discharged per hectare of cut flower production [22]. The identified parameters whether core indicators or sub-indicators, it used to point out the environmental problems that occurred by flower farms in the districts analyzed using Excel and evaluation was done based on average materials flow in the farms per hectare of any activities [23].

3. Results and Discussion

Based on the methodology used in the study, all necessary data collected from an onsite data collection system using inventory assessments. This inventory data collection included the fundamental materials input-outputs in the flower farms cradle-gate processing system based on LCA as per ISO14044 which is organized in the following Table 1 (based on the selected functional unit).

Table 1. Input-output inventory results

No	Indicators			Unit	Input	Output	Consumed
1	Solid materials	Leaf and stems		Kg	-	86000	-
		Cut flower wastes		Kg	-	5220	-
		Paper		Kg	1500	20.26	1479.74
		Cardboards		Kg	4100	30.12	4069.88
		Plastic		Kg	3200	20.9	3179.1
2.	Water	Used water		m^3	28800	7200	21600
3.	Chemical	Fertilizer	DAP	Kg	650	-	-
			UREA	Kg	450	-	-
		Pesticide	All	Kg	50	-	-
4.	Energy		Diesel	Kg	48	-	-
			Petrol	Kg	35	-	-
			Electricity	Kwh	2.55	-	-

Planting media in the flower farms: In flower farms, media is the area that is prepared for the plantation of cut flowers in the greenhouse or open fields of the flower farms within a furrow alignment form. This study assessed primary and secondary data from 21 flower farms that existed in the district. As understood from collected data, the district flower farms have used both soil bed media and hydroponics media. All most all flower farms in Wolmera district have used soil bed as planting media because of its cost-effectiveness, but using soil bed in flower farms environmentally less significant when compared with hydroponic beds because hydroponic bed systems have the recycling probability of wastewater as data obtained from flower farm managers and Environmental protection authority office of the district [24-26].

3.1 Cut Flower Products

Cut flower products are annually produced cut flowers may be measured in stem/tons/kg/bunch that supplied for marketing purposes (export/for local markets). For this study to get the annual production of cut flowers more than twenty questioner papers were distributed to flower farms in the areas and tangible data were collected from its sources. The growth production of cut flower in Wolmera district flower farms was about 85520 kg/ ha production yields were harvested throughout the one-year production life cycle for marketing purposes. This has a great role in the country's economic developments as stated that export earnings further diversifying Ethiopian exports and becoming an important contributor to Ethiopia's economic developments [27]. Despite this, an average nearly 5220 kg of cut flower rejected during packaging process as waste materials and through cut flower development process huge amount of stem and leaves were wasted to the environment which has similar amount with products per year in average as data obtained from the flower farms managers office and EPA of the district. In the same way, no route tries to change these solid wastes to any beneficiary assets in the flower farms [28]. The rejected cut flower wastes, stems & leaves were disposed of and burnt in the firms as agricultural residual biomass. Any agricultural residual biomass burnt in the farms emits emission of GHG (CO_2, N_2O, and CH_4) (IPCC 2006). In this study based on IPCC standards emissions emitted to the atmosphere were calculated using IPCC (2006) guidelines related to agricultural residue biomass burning emission factor standards [29]. Based on this guideline the results of evaluated GHG emission from burnt floricultural residue and biomass aggregated in Table 2.

3.2 Water Consumption and Analysis

The total water consumptions in flower farming are originated from groundwater, surface water, and harvested

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water, normally more percentage of demand fulfilled from groundwater. This similar Ethiopia flower farms use more present water from groundwater [30]. It is belonging that flower farms use a high amount of water just like other common horticulture production. But, the use of water in floriculture depending on the farm area, climate change, soil types, and water using mechanism in the activities and flower farms daily water consumption is varying from farm to farms. In the current study, Wolmera district flower farms were used on average 28800 m^3/ha as input to process cut flower production activities and 7200 m^3/ha wastewater was discharged to the environments per year as data organized from flower farms managers (21 in number) and district EPA office. But, even if horticulture production is known by using too many intensive resources like land, water, and chemicals [31]; the amounts of water consumption in Wolmera district flower farms have the highest values when compared with previous articles. This indicated that flower farms in Wolmera district have used too much water which results in GHG emission to the atmosphere & drains the wastewater directly to the field and rivers that supplying nutrients like PO_4, NO_3, and NH_3 which support the process of eutrophication or acidification. This situation restricts the value of water for a different purpose in the communities [32]. This assures that the boundless use of water in flower farms can lead the area to scarcity of groundwater and can cause a high amount of wastewater drain to environments. In general, the wastewater discharged from the flower farms to the fields and rivers could facilitate the eutrophication and acidification in the areas by supplying N, P with their compounds respectively and these all emission to atmosphere, territory and aquatic body quantitatively estimated in the next portion at flower farm emission evaluation parts from per hectare emitted wastewater [33].

3.3 Solid Waste Analysis

The most solid waste observed in the flower farms were plastic wastes, paper wastes, cardboards, flower stems, leaves, and cut flower residues. As data collected from different sources of the district office and flower farms managers (21 in numbers) the total amounts of stems and leave waste disposed of were an average of 86000 kg/ha and cut flower wastes during packaging 5220 kg/ha were wasted from the farms and 20.26 kg/ha paper wastes generated from 1500 kg/ha input papers, 30.12 kg/ha of cardboard wastes from 4100 kg/ha inputs and 20.9 kg/ha of plastic materials wasted from 3200 kg/ha of plastic materials input to the flower farm process were disposed to the environments, which shown in Figure 3. To dispose of the wastes in flower farms, there are different types of waste disposal mechanisms that including landfill, incineration, anaerobic digestion, and recycling wasted materials [34]. But, in the Wolmera district, all almost all flower farms have used open burn of the farm's residual biomass infield because of fear of the cost to build modern and acceptable disposal mechanism, but a little bit of wastes has burnt in incinerators in some of the flower farms. Open burning of agricultural residues biomass generates GHG emission (IPCC 2006). In the district, all flower farms recycling and changing to the beneficial asset is zero as data obtained (gathered) from Wolmera district environmental protection & climate change authority office and physical observation of the farms at sites except some percent of plastic wastes. The GHG emission emitted from residual biomass burning in farms estimated using equation listed in chapter three that based on IPCC 2006 agricultural residues biomass burning guideline in the emission estimation process and the GHG emission that generated from the farms evaluated and discussed in emission estimation parts [35].

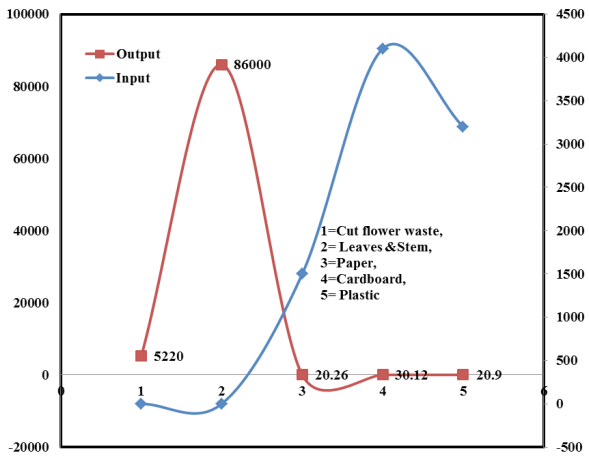

Figure 3. Solid waste types disposed from flower farms

3.4 Chemicals Used in the Farms

Ethiopia's floriculture industries use more than 300 types of chemicals in rose production farms (Kassa 2017). In the same way to get chemical types used in Wolmera district flower farms in this study sufficient questioner papers were distributed to collect the necessary data from the farms. To aggregate, these data about twenty-one questioner papers were distributed and collected the necessary data on chemical type and the number they used at each flower farms. The collected data indicate that about 156 chemical types were applied in the Wolmera district flower farms. These all chemicals are mostly used at nursery sites, cut flower plant handling stages and at packaging rooms for prevention and preservation purposes. Most

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chemicals used in flower farms are fertilizer and pesticides that are stated separately [36].

Fertilizer

Flower farms in Ethiopia used more than 30 types of fertilizers to supply sufficient nutrients to the harvesting plants. Also, Wolmera flower farms are used different types of fertilizer which involves ammonium sulfate, potassium sulfate, potassium nitrate, potassium phosphate, ammonium phosphate, and urea, but the current study focused on two main fertilizers were used in the farms with the highest percentage which included DAP & UREA [37]. In this study, as data collected from flower farms office directly at on-site data collection system, an average Wolmera district flower farms use 650 kg DAP and 450 kg UREA per hectare of cut flower production within a year. The farms used much amount of fertilizer that can lead the process to environmental pollution in case of GHG emission, nutrient discharging to the rivers that support the eutrophication or algal developments in river bodies and increase the acidity of the rivers in the areas as evaluated from laboratory analysis. The study mainly focused on estimating both emission types (GHG &nutrient discharged to rivers) emitted to environments from the farms as a whole [38]. The GHG emission was evaluated using a different equation based on the number of materials used/disposed of and emission factors to estimate NH_3, N_2O & CO_2 emitted to air with a correction factor of each gaseous as per IPCC 2006 standards related to synthetic nitrogen fertilizer, but the nutrients discharged to the rivers were estimated from laboratory results related with wastewater discharged per hectare of cut flower productions. The most GHG emissions evaluated in this study from wastewater discharged or emission were N_2O, CO_2, and CH_4; also, NH_3 emission estimated from 8% of applied nitrogen fertilizer in the farms [39].

Pesticides

Ethiopia flower farms used more than 200 types of pesticides to control macro and micro-organism that affect the developments of cut flowers. Based on this statement in the current study more than 156 chemical types were collected to assess the banned chemical used and estimate emission to air in the farms. Wolmera flower farms on average about nearly 45 kg of pesticides used per hectare of cut flower production within a year. The pesticide used in flower farms has the ability of emitting pollutants into an atmosphere that cause climatic changes or pollution [40]. This pesticide emission into the atmosphere was estimated which indicated that 30-50% of pesticide sprayed emitted into the air in case of volatilization and air drafting system which organized in Table 2.

3.5 Energy Consumption Analysis

The most energy sources in Wolmera district flower production farms are electricity, diesel, and petrol to facilitate any activities in the firms. Also, they are mainly depending on non-renewable energy sources rather than supporting renewable energy sources. Energy in the farms was used in the cooling room, in the office, lighting in the compounds, transportation, and for irrigation purposes. But current study focused on energy used for transportation and irrigation water pumping which is included in the system boundary. Total energy consumes per hectare of cut flower production were 3.55 kWh electric power,50 kg of diesel oil, and 35 kg of petrol. The energy used in flower farm production emits GHG to the environment that has great value in environmental pollution. Most GHG emissions caused by these sources of energy used in the farms are CO_2, N_2O & CH_4. These were estimated concerning on heavy-medium duty vehicle emission factor adopted from IPCC 2006 guideline. The result and discussion of the evaluated emission were aggregated in the emission estimated portion is mentioned in Table 2.

Table 2. GHG emission results from different input-output materials.

No	Indicators		Emission	Unit	Values
1.	Fertilizes	DAP	CO_2	Gg/yr	$3.17*10^{-4}$
			N_2O	Gg/yr	$1.02*10^{-6}$
			CH_4	Gg/yr	$1.85*10^{-4}$
			NH_3	Gg/yr	$6.31*10^{-5}$
		Urea	CO_2	Gg/yr	$1.41*10^{-4}$
			N_2O	Gg/yr	$4.56*10^{-7}$
			CH_4	Gg/yr	$3.265*10^{-9}$
			NH_3	Gg/yr	$4.37*10^{-5}$
2.	Residual biomass burn (BB)	Total residues	CO_2	Gg/yr	7.155
			N_2O	Gg/yr	$6.39*10^{-3}$
			CH_4	Gg/y	0.24643
3.	Energy used	Diesel fuel	CO_2	Gg/yr	$4.896*10^{-4}$
			CH_4	Gg/yr	$2.448*10^{-4}$
			N_2O	Gg/yr	$2.304*10^{-4}$
		Petroleum fuel	CO_2	Gg/yr	$1.988*10^{-4}$
			N_2O	Gg/yr	$1.68*10^{-4}$
			CH_4	Gg/yr	$1.785*10^{-4}$
		Electricity	CH_4	Gg/yr	$3.06*10^{-3}$
			N_2O	Gg/yr	$2.55*10^{-5}$
			CO_2	Gg/yr	0.072165
4	Pesticides	Emission	All	Gg/yr	0.00002
5.	Waste water	Effluent	CO_2	Gg/yr	2.85
			CH_4	Gg/yr	0.00288
			N_2O	Gg/yr	0.009

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3.6 Evaluation of Emission

Emission is the process of releasing materials (gaseous, liquid & solid substances) to the atmosphere, land, and water bodies that cause great problems in the environments that resulted from a large amount of natural resource consumed by industries [41]. In this study emission of gaseous substances from input and output materials was evaluated based on data collected from its sources. As listed in Table 2 the most known greenhouse gas (GHG) evaluated were CO_2, N_2O, and CH_4 using IPCC (2006) standard and emissive factors (EF) of each GHG. The study mainly focused on the GHG emission from fertilizer used, energy used, and agricultural residue biomass burnt in the farms and wastewater discharged [42]. Agricultural residues are the main sources of GHG emission in the flower farms that emanated from leaves, stems, cut flowers, and decomposable input materials incinerated or burnt in the farms. In the current study, the residual biomass of flower farms burnt in open fields and release GHG to the environments which mostly included CO_2, N_2O, and CH_4 as expressed in Table 2. These GHG emissions were evaluated from residual biomass burnt in the farms as per IPCC (2006). The evaluation expressed that high amount of CO_2 released to the atmosphere among evaluated GHG emitted from other materials in the farms or when compared with N_2O and CH_4 from these sources shown in Figure 4, but N_2O can create GHG about 265 times over CO_2 gases within a hundred years' life spans [43].

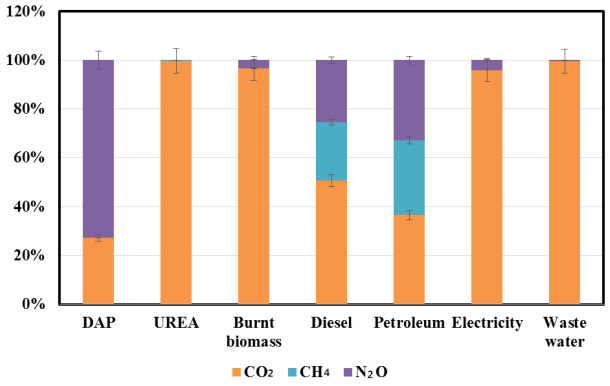

Figure 4. GHG emission from different sources in flower farms

Fertilizer is another type of GHG emission source in agricultural activities and flower farms are one sector of the agricultural system which used a high amount of chemical fertilizers. In this study, only two main nitrogen fertilizers were selected which included DAP and UREA that are used in high percentages in the farms. When these fertilizer types are used in the farms, greenhouse gas is emitted to the atmosphere that can cause global warming by supporting climatic changes (FAO). The basic GHG emitted from both nitrogen fertilizers used in the farms were CO_2, N_2O, CH_4, and NH_4. This GHG emitted from N- fertilizer was also evaluated as per IPCC (2006) standards that included using CO_2, N_2O & NH_3 gaseous from DAP, but for NH_3 using 8% of total nitrogen fertilizer percentages used in the farms as an emissive factor [44]. Also, greenhouse gas emitted from UREA evaluated using the total amount of Urea used to multiply with gaseous emitted emission factors for evaluation of both CO_2, N_2O & CH_4 estimated from global warming potential standards for each GHG emission. NH_3 was evaluated from total urea used per hectare of flower production after decomposition evaluated based on 8% of fertilizer used released to the atmosphere in form of ammonia & 2% release in the form of NOx [45].

$$N_2 + 3H_2 \leftrightarrow 2NH_3$$

$$2NH_3 + CO_2 \leftrightarrow NH_2CONH_2 + H_2O$$

As mentioned in Table 2 and shown in Figure 4 high percentages of CO_2 emanated from urea and high percentages of N_2O from DAP released into the atmosphere when compared with other types of GHG emitted from both types of fertilizers. This can cause atmospheric pollution and climatic changes in the environments. The other types of GHG emission sources in the current study were the gaseous emitted from energy sources used in the farms that included energy for transportation and water pumping systems. Different types of energy sources used in flower farms, but the current study only selected the major energy sources used in the farms which included diesel fuel, petroleum fuel, and electricity power [46]. For all energy sources in the farms major GHG (CO_2, N_2O & CH_4) emitted as fundamental emission from the energy used were evaluated for diesel fuel, petroleum fuel and electricity. The amount of material used and emission factors of each GHG emitted from all energy sources used in flower farms and is based on medium to heavy-duty vehicles for emission factor of each GHG emitted. It can be observed that high percentages of CO_2 released to the atmosphere from diesel fuel and low amount of CO_2 released from petroleum when compared with each other or compare three of them that can bring climatic changes in the areas [47].

Wastewater discharged from flower farms is another type of material output that can cause environmental pollution and emit greenhouse gases to the air. In the current study, the other materials that can cause GHG emissions were wastewater discharged to environments from flower farms. The main greenhouse gas emitted from wastewater included CO_2, N_2O, and CH_4 that evaluated in this study. The CO_2 gas emission in the study estimated using hundred-year time horizon global warming potential (GWP =310 for N_2O and GWP = 21 for CH_4) that collected from IPCC 2006

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standards and both N_2O and CH_4 estimated values. Based on evaluated results the amount of GHG emission from wastewater (effluent) to the atmosphere was greater than the other types of GHG emitting sources i.e. wastewater discharged from flower farms has great values to increase global warming by supplying a huge amount of GHG rather than other types of GHG emitting materials. The emission from pesticides in this study evaluated from a total pesticide used per year in the farms based on emissive factor. The reason behind to released on atmosphere and soils which depend on 30-50% of pesticides sprayed emitted to air in case of volatilizations and air drafting that mainly focused. Estimation of pesticide emission most of the time based on air condition, time, application methods, application systems, application skill, and types of pesticides [48]. Using this system, the GHG emitted from these chemicals evaluated totally from pesticide applied in flower farms that highly supports the climatic changes of the environments by inducing about 0.00002 Gg/year [49].

3.7 Emission of Nutrients to the River with Wastewater

The number of nutrients discharged to the river and nearby lands was evaluated from the results of effluent sampled that examined by the laboratory and the amount of wastewater discharged to the environments. As shown in Figure 5 PO_4, NO_3, NH_3 & SO_4 were the main nutrients that were discharged to the environments which support the eutrophication and acidification i.e. N, P, and their compounds are the major causes of eutrophication and acidification respectively [50]. Acidification occurred by NH_3, NO_X, SO_X by releasing H^+ which has the potential to acidify soil and water bodies. In this study, the main supporters of acidification are SOx, NH_3, and NOx and the main eutrophication supporter nutrients are PO_4, NH_3, NO_3.

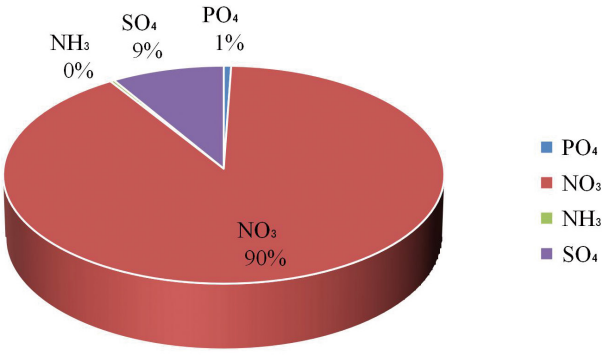

Figure 5. Nutrients support eutrophication and acidification of water bodies

As mentioned in Table 2 Wolmera district flower farms released a high dosage of chemicals that supports eutrophication and acidification into the environments as understood from estimated results. In general, the assessment evaluation involves the most influential emission which focused on GHG emission and wastewater emission to the environments. Both emission types estimated using international standards and laboratory analysis using the emitted discharge to the environments. The fundamental emission of GHG estimated from all input-output materials was CO_2, N_2O, CH_4 & NH_3 which has high potential to increase global warming and emission of wastewater to environments; also used to estimate chemical nutrient (PO_4, NO_3, NH_3, and SO_4) added to the rivers that support the development of eutrophication and increase acidification in the ecosystem after chemical fertilizer and pesticides react with water. In addition to these CO_2 has a great value to add acidification to environments especially in water bodies that included rivers, lakes & oceans [51]. According to this statement, CO_2 released into the air react with water and creates water body acidification that can harm the organisms in water and users of the water resources. Acidification of the water body could occur during atmospheric CO_2 reaction with water as following reaction process and increase H^+ in water bodies (oceans, lakes, rivers) of CO_2 from the air. In general, CO_2, SO_4, like compounds resulted in acidification when they reacted in the atmosphere with water droplets or precipitation [52].

$$CO_2 + H_2O \leftrightarrow H_2CO_3$$

$$H_2CO_3 \leftrightarrow HCO_3^{1-} + H^+$$

4. Conclusions

Wolmera flower farms consume too many resources and disposed of/discharged a huge amount of wastes to the environments which directly or indirectly influence the environment & its components. In the company, input-output materials were assessed & identified by using inventory and sampling data collection methods that are supported by ISO14031 standard integrated with LCA. An important data was collected from its sources (at the site) and GHG (CO_2, N_2O, CH_4 & NH_3) emission emitted to environments were evaluated from fertilizer (DAP & UREA), floriculture biomass residue burns in farms, energy consumed (diesel fuel & petroleum), pesticide applied and wastewater discharged to an environment using IPCC 2006 from inventory data aggregated. These all GHG emitted to environments can increase global warmings. Similarly, the basic cause of eutrophication

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and acidification materials (NO_3, PO_4, NH_3, SO_4 from wastewater & N, P from soil) were evaluated from laboratory results. In general, the farms have low operational performances and environmentally less significant. To solve these like challenges in flower farms they must follow internal and external combined or linked environmental performances evaluation. Therefore, this systematic environmental management tool is used to lead the flower farms to evaluate an ability they have to manage impacts of an environment instead of missed EIA documents during construction.

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ARTICLE

Cascade Tank Water Quality Management: A Case Study in *Thirappane* Tank Cascade System, Sri Lanka

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ABSTRACT

Tank cascade system (TCS) is a series of tanks located in a meso-catchment and has been accepted as a Globally Important Agricultural Heritage System found in Sri Lanka. Ecosystem components of the TCS play a major role in purifying water within the system. This study attempted to investigate the water quality status and the farmers' willingness to rehabilitate the ecosystem components of the Thirappane TCS. Drinking and irrigation water quality parameters were tested in 34 locations and drinking and irrigation water quality indexes were calculated. Participatory rural appraisal and a questioner survey were conducted to gather social data. Water of TCS was observed to be appropriate for irrigation but not for drinking during the *Maha* cropping season. Based on the results of the Nitrate (as NO_3^-) and Total Phosphate (as PO_4^{3-}), water of TCS can be categorized as eutrophic. Presence of ecosystem features of tank cascade system, annual income of the respondents, satisfaction on the quality of water for drinking, and the awareness about the tank cascade system significantly influenced the participatory decisions of the community on the rehabilitation of TCS. This study shall be an example and an eye opener to formulate sustainable tank cascade management plan.

1. Introduction

A watershed system provides a range of valuable ecosystem services which can be categorized as provisioning of food, water, fibre and fuel; regulating droughts, flood and water purification; cultural covering providing humans with recreational, spiritual and aesthetic values and supporting services such as basic ecological properties/ processes (eg. soil formation) [1]. Many of these functions are related to the water and its suspended and dissolved constituents [2]. Water purification is a vital function of an ecosystem. Therefore, understanding the ecosystem functions and promotion of eco-engineering structures and techniques is vital in water purification as those are no regret and multi beneficial approaches.

Sri Lanka is a tropical island demarcated into three main climatic zones wet, dry and intermediate. Rainwater harvesting with man-made small reservoirs or "*Wewa*"s

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(tanks) is the major source of water for irrigation and drinking in the dry zone of Sri Lanka. These tanks were built by the early inhabitants in a cluster arrangement aligned with the water flow and are now referred to as Tank Cascade Systems (TCS). TCS of Sri Lanka is a special kind of watershed within which a series of tanks are located one over the other in terms of water flow hydraulics aligned with respect to the natural flow of water. TCS also provides the production, regulatory, supporting and other cultural services similar to that of a general watershed. TCS has been acknowledged as a Globally Important Agricultural Heritage Systems (GIAHS) by the Food and Agriculture Organization [3] because this system is an improved agricultural system managed with time tested indigenous techniques and it comprises of outstanding landscapes of aesthetic beauty and resilient ecosystems. Proper functioning of ecosystem components and bio engineering structures such as the earthen dam (*We-kanda*), spillways (*Pita Wana*), sluice gates (*Sorrowwa*), valve pit (*BissoKotuwa*), upstream conservation bund (*iswetiya*), upper peripheral gentle sloping land (*thaulla*), closer catchment (*wew ismaththa*), upstream wind barrier made of tree plantations (*gasgommana*), downstream wind barrier, located in between the sluice and paddy (*kattakaduwa*), and land strip around the hamlet for protection (*tisbamme*) warrant the improved quality, quantity and sustainability of the water of the TCS. The importance of these components is highlighted in many publications and attempts have been reported to prove those functions scientifically [4,5]. The application of eco-engineering components and the use of existing structures need to be fully utilized as these are non-regret approaches and have multiple benefits. This time tested system of rainwater harvesting is a sound adaptation strategy to face consequences of climate change and variability related issues.

However, at present the system is degraded due to changes in land use pattern, improper land management practices, and the lack of due consideration for the ancient ecosystem components and the structural components by the present planners [6]. Moreover, population rise, urbanization and modernization might have impaired the services of TCS. Changes in agricultural practices such as heavy dependence on increased amount of inorganic fertilizer, pesticides and cultivation neglecting soil conservation [7] may have direct impact on TCS where main land use is in agriculture. It is evident that agro chemicals improve the crop productivity while leading to soil contamination and transfer of contaminant to food chains causing several human health problems [8]. One such health issue is Chronic Kidney Disease of unknown aetiology (CKDu) prevailing in both dry and intermediate zones of Sri Lanka. Dry and intermediate zones of the country are the home of these ancient TCS in which more number of patients are reported and many of them are farmers. Aetiology of CKDu is still a mystery, however it is hypothesized that the agro chemicals might be the cause for CKDu [9]. This manuscript does not aim to discuss the aetiology of CKDu but attempts to investigate the present status of water quality and farmers' perception on possible water quality improvement and thereby to introduce best management practices for the farmers in order to minimize the impairment of water quality of the TCS. Abeysingha *et al.* [6], have shown that if ecosystem components of TCS are rehabilitated, spreading of CKDu could be controlled, even with a control measure such as the application of recommended doses of inorganic fertilizers. As a basic step, the water quality status of the entire cascade need to be understood to formulate a proper watershed management plan. In such watershed management plan, the stakeholder commitment, participation and their perception on the rehabilitation of TCS are vital. Therefore, this manuscript attempts to discuss the water quality status both with respect to drinking and irrigation in the area during the major rain (*Maha*) cropping season and the community perception on rehabilitation of ecosystem components of the TCS in improving water quality status.

2. Material and Methods

2.1 Study Site

The *Thirappane* cascade system (TCS) is located about 25 km south of *Anuradhapura* city in Sri Lanka. It is one of the typical of hundreds of irrigation tank cascade systems that are found in the dry and intermediate zones of Sri Lanka. *Thirappane* tank cascade system is mainly comprised of five tanks, *Vendaramkulama*, *Badugama*, *Bulankulama*, *Meegasagama* and *Allisthana* tanks (Figure 1). In this tank system, command area of one upstream tank is a part of catchment of the next downstream tank and ultimately all water of these tanks are emptied to *Thirappane* tank, a larger tank. Administratively this area covers *Thirappane* Divisional Secretariat Division and *Thirappane* Agrarian Service Division of *Anuradhapura* district. According to available statistics in the Divisional Office of the Department of Agrarian Development, there are three farmer organizations in the TCS. It is observed in this TCS, the modernization has `changed the sustainable traditional farming practices and also the human encroachments have disturbed the eco-system components of the TCS. Figure 2 shows some prominent structural and ecosystem components of *Meegasagama* tank which is a

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part of TCS and the map was made during the dry season.

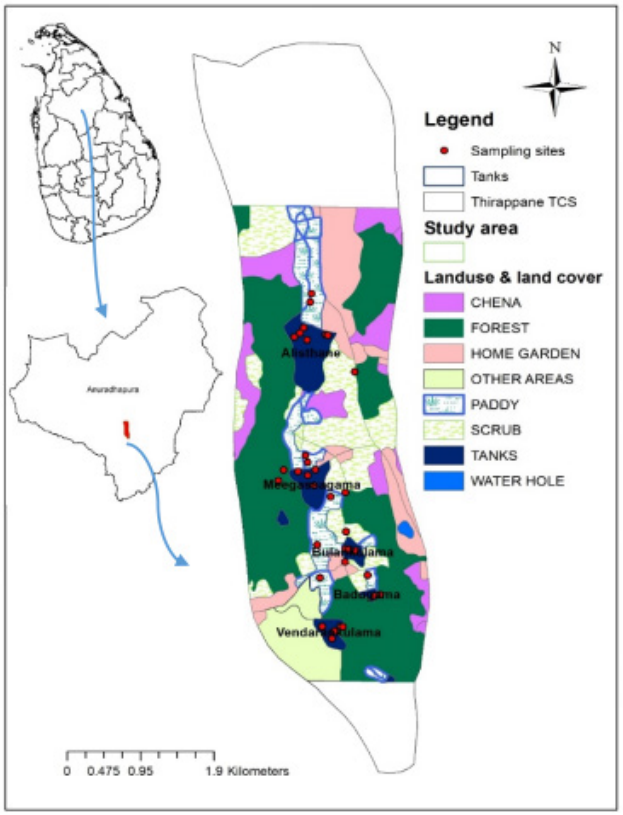

Figure 1. The geographical locations of *Thirappane* Tank cascade system, studied area, tanks, land use, land cover and the water sampling points. The direction of water flow is towards north.

Figure 2. Part of *Thirappane* tank cascade showing Meegassagama tank and its prominent components (Google Earth map taken during dry season)

2.2 Water Quality Survey

Five main tanks (*Vendaramkulama*, *Badugama*, *Bulankulama*, *Meegasagama* and *Allisthana* tanks) and their catchments and command areas were selected to monitor the water quality status in the TCS. The selected area of water quality monitoring represented the entire TCS except for the most downstream section of the TCS. Community in the area supported to select 34 sampling points which include the tank water spread area, catchment and the command area. Attention was drawn to represent the entire tank water when particularly choosing water sampling sites of the tanks. Surface water quality sampling sites of these five tanks, their catchments and command areas are shown in Figure 1. However, as per the definition of TCS, the command area of one upstream tank becomes the catchment area of the next downstream tank. Water was sampled during the early hours of the day (around 9.30 to 10.30) on 10th January 2019 (Fist sampling), 11th February 2019 (Second sampling) and 28th April 2019 (Third sampling). Two samples were taken from each of these 34 sites and analysed separately. However, sampling was limited to three times because of the non-availability of water in the sampling sites because of the prevailed drought and the higher evapotranspiration. First sampling day represented the full supply level and water levels of the area were medium during the second and third sampling times according to the community feedback. Sampling sites have to be little shifted during the third time sampling due to the water level receding. During this time, the major cropping season of the dry zone, the *Maha* (October to March) has been commenced and the most of the initial cultivation practices have been finished. This area receives a total average annual rainfall of about 1,445 mm and also the area receives more water during October to March period especially from the North East monsoon rains.

The collected water samples were tested for various important water quality parameters and some parameters were derived based on the results of the laboratory tested parameters. As physical parameters, turbidity, temperature and colour and as physico-chemical parameters, EC and pH were tested using standard methods. As chemical parameters, chloride (as Cl^-), total alkalinity (as $CaCO_3$), free ammonia (as NH_3), nitrate (as NO_3^-), fluoride (as F^-), total phosphate (as PO_4^{3-}), sulphate (as SO_4^{2-}), HCO_3^- (as $CaCO_3$), CO_3^{2-} (as $CaCO_3$), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) were measured using standard methods (10). Moreover, Na, Ca, Mg, K, Cu, Cd, Pb, As, Cr, Mn, Zn, Ni, Hg, Fe and Al were also tested as metallic elements using Inductively Coupled Plasma Optical Emission Spectroscopy

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(ICP-OES, Thermo, icap7400DUO MFC) following the method [10] in all sampling points.

Other than the above-mentioned parameters, Residual Sodium Carbonate (RSC), Sodium Adsorption Ratio (SAR), Sodium Percentage (SP), Kelly's ratio (KR), Magnesium hazard (MH) and Permeability index (PI) were also determined to test the suitability of water especially for irrigation.

Residual Sodium Carbonate (RSC) index was calculated from the difference of total carbonate and bicarbonate with total calcium and magnesium [11].

$$RSC\,index = [HCO_3^- + CO_3^{2-}] - [Ca^{2+} + Mg^{2+}] \quad (1)$$

SAR was calculated from the ratio of sodium to calcium and magnesium [12].

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (2)$$

Sodium percentage (Na %) was calculated using the following formula,

$$Na(\%) = \left(\frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + K^+}\right) \times 100 \quad (3)$$

The Kelly's ratio was measured using the expression [13],

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (4)$$

The Magnesium hazard (MH) was calculated using the equation [14],

$$MH = \left(\frac{Mg^+}{Ca^{2+} + Mg^{2+}}\right) \times 100 \quad (5)$$

Permeability index was calculated using the following equation

$$PI = \frac{Na^+ + \sqrt{HCO_3^- x100}}{(Ca^{2+} + Mg^{2+} + Na^+)} \quad (6)$$

All ionic concentrations are expressed in meq/L when calculating SAR, RSC, KR, MH and PI. Following Brindha & Kavitha [15]; Houatmia *et al.,* [16], this study calculated the Irrigation water quality index (IWQI) and also the Drinking water quality index (DWQI) only for the tank water considering the FAO and SLS guidelines respectively.

Irrigation water quality index IWQI

$$IWQI = \Sigma(Wn \times Qn) \quad (7)$$

Wn = Unit weight of the nth parameter

Qn = Quality rating or sub index corresponding to the nth parameter

$$Wn = K/Sn \quad (8)$$

K = Proportionality constant which is computed by

$$K = 1/\sum_{i=1}^{n} \frac{1}{S_n} \quad (9)$$

$$\sum_{i=1}^{n} \frac{1}{S_n} = \frac{1}{S_{pH}} + \frac{1}{S_{EC}} + \frac{1}{S_{Ca}} ..... + \frac{1}{S_n} \quad (10)$$

Sn = Standard permissible limit in water for the nth parameter

$$Qn = 100 \times [Vn - Vi]/[Sn - Vi] \quad (11)$$

Where

Vn = measure value of the nth parameter in water at a sampling location

Vi = ideal value of the nth parameter in water (0 for all parameters).

Study used EC, MH, RSC, SAR, Na %, NO_3^- and PI for the calculation of IWQI and the highest suitability limits were taken from the [15] and [17]. Similar calculation method was used to calculate the DWQI. Turbidity, pH, EC, NH_3, NO_3^-, SO_4^{2-}, PO_4^{3-}, Alkalinity, TDS, Na, Al, Ca, Cl, COD, Cu, Fe, F, Mn, Mg, Zn were used in calculating the DWQI and highest desirable limits of SLS 614 [18] were used and where there is no Sri Lankan (SLS) standard, study used the WHO drinking water guideline (2011).

2.3 Participatory Rural Appraisal (PRA) and Questioner Survey

This research project used Participatory Rural Appraisal (PRA) in order to establish community participation as a tool in assessing the present status of the TCS and changing management practices of the farmer community. This programme was conducted in two stages with an initial meeting and a detailed second meeting. Transect walk was held after the second day meeting to verify the information gathered during two days. Transect walk reviewed the ecology of the catchment of the tanks, current situation of the cascade features, present livelihood patterns, farmer practices, fertilizer application patterns etc. Around 40

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participants attended the activity including the extension field officers. In addition to the PRA activity, a pre-tested questioner was administered to get some specific information on the agricultural practices, and the level of awareness of ecosystem components of TCS. For this survey, 60 farmers were selected which was 1/3 of total members of each farmer organizations. Though there were five tanks, only four farmer organizations existed in this TCS (Table 1). Even though, there are separate farmer organizations. These farmers are sociologically connected as they live in the same cascade and thus the farming practices are the same.

Table 1. Farmer organizations and total number of farmers selected for the survey.

Name of the tank	Farmer organization	Total number of farmers	Number of farmers selected for the interview
Alisthana	*Samagi*	20	8
Meegassegama	*Parakum*	58	24
Badugama	*Vendarankulama*	5	2
Vendarankulama		36	15
Bulankulama	*Pubudu*	25	11
Total number of farmers		144	60

The survey data were analysed using descriptive statistics and logistic regression to identify the factors affecting the farmers' willingness to rehabilitate the TCS particularly improve the water quality.

3. Results and Discussion

Safe drinking water is a necessity for humans. Quantity and quality of crops are determined by the availability of water in sufficient quality. Water quality, tested by assessing the properties of water against a set of standards, was used to determine whether water available is suitable for drinking, irrigation or safe for the environment in this TCS.

During the PRA activity, farmers in the area helped in choosing the water quality monitoring sites by identifying drainage canals from one tank to the downstream tanks. Also they briefed the causes for pollution in the area. First, the water quality status of the TCS and then the farmers' perception towards the ecosystem components of the TCS in purifying the water will be discussed.

3.1 Variation of Physical and Physicochemical Water Quality Parameters

Physical and physicochemical parameters such as pH, turbidity, Electrical Conductivity (EC), Total Suspended Solids (TSS) and Total Dissolved Solids (TDS) were tested over the entire cascade and their average results of three times sampling are discussed.

pH.: Measurement of pH indicates the acidity or alkalinity of the water. Standard pH range given by SLS 614 (18) drinking water quality standard is 6.5 to 8.5 (Table 2). Average pH of water in the entire TCS is within the limits stipulated by SLS 614 [18] drinking water quality standard. Also this water is within the suitability range of pH proposed by FAO irrigation water quality limits (Table 2).

Table 2. Statistical summary of the physical and chemical water quality parameters tested over surface water (average over 34 sites)

Parameter	Max	Min	Mean	SD	SLS	Irrigation-Standard*
Turbidity (NTU)	27.75	1.83	6.54	5.35	2.00	2.00
pH	7.68	6.60	7.16	0.28	6.5-8.5	6.5-8.4
Electrical Conductivity (µS/cm)	1215.50	117.70	403.02	242.93		< 700
Chloride (as Cl^-)	159.85	9.45	51.24	37.83	250.00	< 140
Total Alkalinity (as $CaCO_3$)	451.00	44.33	121.23	90.80	200	
Free Ammonia (as NH_3)	0.30	0.00	0.09	0.07	0.06	
Nitrate (as NO_3^-)	14.23	3.48	5.83	2.13	50.00	< 5
Fluoride (as F^-)	0.85	0.00	0.12	0.19	1.00	
Total Phosphate (as PO_4^{3-})	3.76	0.22	0.69	0.59	2.00	
Sulphate (as SO_4^{2-})	29.54	0.00	4.00	6.82	250.00	
HCO_3^- (as $CaCO_3$)	449.35	41.00	114.81	92.59		
$CO3^{2-}$ (as $CaCO_3$)	26.67	0.00	6.36	7.58		
BOD	7.35	0.20	2.12	1.41		
COD	71.55	5.10	29.58	14.48	10.00	
TSS	41.00	2.00	6.40	6.72		
TDS	745.75	88.00	234.90	145.08	500.00	

Note: All units are mg/L unless otherwise mentioned. SLS: Sri Lanka Standard for potable water quality; *Irrigation water quality standard [19].

Turbidity:

Turbidity of surface water including the water in the command area was in the range of 1.4 to 27.7 NTU with a mean of 6.5 NTU (Table 2). Even the mean turbidity was higher than the value given for drinking water by the SLS 614[18]. According to US EPA, turbidity level lower than 2 NTU is only suitable for directly consumed crops and unrestricted irrigation. However, Spain recommends a level lower than 10 NTU for vegetables especially for

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waste water fed irrigation [20]. A high level of turbidity may influence on the performance of the irrigation facility, and can lower the hydraulic conductivity of the soil and pollute the soil surface through surface flow. In addition, through the field survey with farmers, study identified the areas which need to be focused on the turbidity reduction.

Electrical Conductivity (EC):

EC is a measure of dissolved salts in water and the maximum allowable level of conductivity for drinking water is not given by SLS 614[18] or WHO drinking water quality limits. The results show that the measured conductivity of all water samples ranges from 117.7 µS/cm to 1,215.5 µS/cm, and the average conductivity value is 403 µS/cm (Table 2). However for irrigation water, FAO has stipulated EC values less than 700 µS/cm is suitable for any crops. Thus the water even in command area of the TCS is suitable for irrigation water in terms of EC.

Total Suspended Solids (TSS) and Total Dissolved Solids (TDS):

TDS consists of inorganic matters and small amounts of organic matter, which are present as solution in water. TDS in water varied from 88 to 745mg/L with a mean of 234 mg/L (Table 2). The standard or allowable value of the TDS set by SLS 614 [18] is 500 mg/L. TDS during the study period is good for drinking purpose except for few areas. TSS is organic or inorganic matter suspended over the water and it varied from 2 to 41 mg/L in *Thirappane* surface water.

3.2 Variation of Chemical Water Quality Parameters

Alkalinity:

This parameter is an expression of buffering capacity of water and is related to hardness because the main source of alkalinity usually results in from carbonate rocks (limestone) which are mostly $CaCO_3$. Fish and aquatic life is protected by the alkalinity as it buffers against rapid pH changes [20]. Fish naturally breed in these tanks. Therefore required level of alkalinity is important for the aquatic life of these tanks. Alkalinity of TCS varied from 44 to 451 mg/L with a mean of 121 mg/L. The standard values for the alkalinity given by SLS 614 is 200 and the mean value observed is below the critical level.

Chloride and Fluoride:

Chlorides and Fluorides are anions found in natural water. The chloride content normally increases in parallel to the increase in the mineral contents. The distribution of chloride content values, ranges from 9 to 160 mg/L with the mean value of 51 mg/L and are within the permissible limits.

Generally, considerable content of fluoride is observed in the groundwater (sometimes in excess of 5 mg/L) in the Dry Zone, in the North Central Province [21]. However, the surface water doesn't contain high fluoride content and this study also observed a mean value of 0.12 mg/L and which is within the permissible level of SLS 614 for drinking water.

Carbonate and bicarbonate

Carbonate and bicarbonate values were used to analyse the residual sodium carbonate (RSC) values of the TCS. Water containing a high concentration of bicarbonate has a tendency for calcium and magnesium to precipitate which will lead to a reduction in the concentration of calcium and magnesium and a relative increase in sodium. HCO_3^- (as $CaCO_3$) and CO_3^{2-} (as $CaCO_3$) concentrations varied from 41 to 449 mg/L and 0 to 26 mg/L respectively in the TCS.

Nitrate (as NO_3^-) and Total Phosphate (as PO_4^{3-}):

It is recorded that North Central Province where *Thirappane* TCS is located, uses fertilizer in high doses sometimes six to ten times in excess of levels recommended by the department of agriculture, Sri Lanka [22]. The main sources of nitrate and phosphate in water in the area are the excess use of inorganic fertilizer and also rearing of cattle with poor management practices. Mean nitrate and phosphate levels during the studied period of the entire cascade were 5.8 and 0.69 mg/L respectively which are within the recommended level of SLS 614 for drinking water, 50 mg/L and 2 mg/L respectively (Table 2). In addition, the maximum value recorded for phosphate P (3.76 mg/L) exceeded the SLS 614 level for drinking water. These higher concentrated areas of nitrate and phosphate P are located in the drainage canals of command area of *Bulankulama* and *Badugama* tanks respectively. However, these water reach the downstream tanks and total nitrogen and phosphorous in water lead to eutrophication of the tanks. Eutrophication occurs when N content in water reaches 300 µg/L and P concentration exceeds 20 µg/L [23]. Considering these critical values, water of TCS can be categorized as eutrophic. Large number of aquatic weeds could also be observed floating over the water surfaces symbolizing the status of eutrophication of tanks in the TCS.

Free Ammonia (as NH_3):

Ammonia is present in variable concentrations in many surface water bodies and water supplies. It is a product of microbial activity and considered also as an indicator of sanitary pollution. In addition higher ammonia concentration is lethal for the fish and reported that lethal ammonia concentration limits for a variety of fish species ranges from 0.2 to 2.0 mg/L (PG, https://water-research.net/in-

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dex.php/ammonia-in-groundwater-runoff-and-streams). Sri Lanka Standard (SLS 614) for free ammonia in drinking water is 0.06 mg/L. Average ammonia concentration in TCS is 0.09 mg/L and it varied from 0 to 0.3 mg/L. Higher concentration was only observed closer to *Bulankulama* tank which may probably be due to the digestion of leaves in the area according to the field observation.

BOD and COD:

BOD value approximates the amount of oxidizable organic matter by a mixed population of microorganisms while COD is an index of oxygen required in oxidizing the organic compounds present in water by means of chemical reaction [24]. These two indicators are therefore used as measures of degree of water pollution and the waste water strength. COD level of the TCS varied from 5.1 to 71.5 mg/L with a mean of 29.6 mg/L. SLS 614 recommends 10 mg/L of COD for drinking water and therefore the water in the TCS is not in good status as a source of drinking water. SLS 722 (1985) [25], the raw water tolerance limits for drinking water supply specifies BOD 5 mg/L for raw water to be suitable for drinking after treatment. BOD in the TCS was in the range of 0.2 to 7.3 ppm with an average of 2.1 ppm. Therefore this water, especially in the command area contains a higher amount of oxidizable organic matter. These findings are very useful for implementing a tank cascade management plan.

Table 3. Statistical summary of trace elemental water quality parameters tested over surface water (average over 34 sites)

Element	Max	Min	Mean	SD	SLS
Na	68.32	5.17	30.02	15.57	200.00
Mg	87.05	4.33	18.50	16.74	30.00
K	14.02	3.87	5.80	1.90	
Ca	150.55	15.37	42.11	32.13	100.00
Cu	2.80	0.00	0.64	0.85	1.00
Cd	0.00	0.00	0.00	0.00	0.003
Pb	8.00	0.00	1.93	1.75	0.01
As (µg/L)	0.92	0.00	0.10	0.25	10
Hg (µg/L)	0.06	0.00	0.00	0.01	1
Al	0.12	0.00	0.02	0.03	0.20
Cr	0.34	0.02	0.18	0.07	0.05
Fe	4.89	0.38	1.18	0.95	0.30
Mn	1.75	0.00	0.06	0.30	0.10
Zn	8.95	0.01	1.25	1.89	3.00
Ni	0.00	0.00	0.00	0.00	0.02

Note: All units are mg/L unless otherwise mentioned

3.3 Variation of Trace Elements

This study used inductively coupled plasma optical emission spectroscopy (ICP-OES) as an instrument to test the trace element in water of TCS as ICP-OES was noted as the method with satisfactory trueness and precision, sufficiently large linear range and sensitivity enabling to reach low limits of quantification of the determined metals in the water matrix [26]. Variation of trace elements along with the SLS 614 standard limits are shown in Table 3. This study also tested the concentration of heavy metals (Cd, Pb, Cr, Hg) and metalloid (As), as the people in the area suffer from chronic kidney disease of unknown aetiology. Cd and As are suspected to be causative factors for CKDu [27]. However, out of the heavy metal tested, only Pb and Cr exceeded the SLS 614 level. Fe concentration in water was also recorded higher than the drinking water SLS standard (0.3 mg/L). Moreover, maximum limits of Ca, Zn and Mn recorded in TCS water were above the SLS 614 critical drinking water quality limits (Table 3). Thus the water of TCS is not suitable enough for drinking or storing as a source of drinking water in terms of the concentration of trace elements. When drinking water quality parameters exceeded standard critical limits, water needs treatment to be suitable for drinking. However pollution control at the source is much preferred to treatment. These findings highlight the importance of a proper watershed management plan for the area.

Table 4. Variation of the concentration of salt related water quality parameters over the *Thirappane* TCS.

Parameter	Max	Min	Mean	SD	Irrigation-Standard	Reference
RSC (Meq/l)	0.70	0.00	0.12	0.18	< 2.5	(28)
SAR	1.75	0.00	0.68	0.38	< 10	(12)
SP	37.51	0.00	23.61	8.38	< 60	(29)
EC (dS/m)	1.22	0.11	0.40	0.24	< 0.7	(30)
MH	61.24	23.44	42.75	8.89	< 50	(14)
PI	96.18	33.74	65.52	13.10	< 75	(31)
KR	1.22	0.19	0.50	0.22	>1	(13)

3.4 Salinity Sodicity Related Parameters

Soils may become saline or sodic as a result of excessive use of irrigation water with high levels of salts. EC of water is only one indicator which expresses the salinity status of water which is not sufficient to characterize the

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soluble salt content of water. SAR expresses the toxicity effect of irrigation water on crops and degradation effects on soil fertility due to sodium ions. SAR of the surface water of the study area varied from 0 to 1.75 and are within the FAO guidelines limits (Table 4). The Kelly ratio (KR) is also used to determine the hazardous effect of sodium in water for irrigation use. In this study region, it varied from 0.19 to 1.22 in surface water (Table 4). Kelly ratio > 1 is considered to be unsuitable for irrigation. KR of few command areas exceeded the limits while other areas and the mean status of KR is within the safe limit. The RSC indicated the excess of carbonates and bicarbonates over calcium and magnesium in irrigation water. RSC > 2.5 is considered as unsuitable and the water of TCS is within the suitable limits in terms of RSC.

PI is used as a criterion, representing the soil permeability as affected by long term use of irrigation water [31]. In accordance with PI, [31] water is classified as class I (>75%, suitable), class II (25 -75%, good) and class III (<25%, unsuitable). PI of the cascade water varied from 34 to 96 % with a mean value of 65. Thus the water of TCS can be categorized as good for irrigation which may not harm the permeability of soil.

3.5 Drinking and Irrigation Water Quality Index of Tank Water

As several parameters determine the suitability of water for a particular purpose, water quality indices are generally used as a solution by giving different weightage factors for different water quality parameters depending on the suitability limits. In order to assess the suitability of tank water of the cascade, IWQI and DWQI were calculated only considering the results of the water quality parameters measured at tank water quality monitoring sites of five tanks.

Table 5. Average tank water quality in terms of Irrigation and Drinking water quality.

AVG status	Avg DWQI	Avg IWQI
Meegassagama tank	63	22.26
Alisthana tank	36.45	18.22
Bulankulama	53.14	19.97
Vendarankulama	74.41	18.54
Badugama	58.09	15.25

Note: 0-25: Excellent, 26 -50: Good, 51-75 : Poor, 76 - 100: very poor, > 100 : Unsuitable, Adopted from [16]

Irrigation Water Quality Index (IWQI) based on the seven parameters (EC, MH, RSC, SAR, Na %, NO_3 and PI) was calculated from equations 7 to 11, and the classification of water samples was done based on IWQI given as a foot note in Table 5. Average IWQI of water varied between 15.3 and 22.3 in different tanks. According to the classification [16], water of all tanks is excellent for irrigation which is very much suitable for crop growth and also has no detrimental effects on the soil where plants are grown. This water is at present used for irrigation of mainly paddy. As a whole, water during the *Maha* season (high and medium water levels) is suitable for paddy cultivation.

However, this water had been used for drinking purpose since ancient time up to recent past according to the farmers in the area as per the results of the PRA activity. They don't use it now for drinking because of prevailing situation of CKDu incidence in the area and the strongly suspected association of potable water with the CKDu. However, they believe that the surface water is less alkaline and be able to use them for drinking, if they manage the tank cascade system properly. At present, some of them use Reverse Osmosis (RO) water as the drinking water. As such, this study tested the DWQI of all tank water to check the present status of the tanks. As shown in the Table 6, none of the tanks water is excellent for drinking as per the drinking water quality guidelines. The water of *Alisthana* tank is good for drinking in accordance with the parameters tested under high and medium water levels of the tanks. Water of all other tanks is poor according to the classification.

3.6 Social Survey

Stakeholders' involvement is the key to success of watershed management programmes and this study could get the engagement of the main stakeholders even for identifying the drainage paths and selecting water quality sampling sites. First the respondent farming community is queried for a brief description.

Questionnaire survey results revealed that almost all the respondents (100%) were household heads. Of all household heads, 20%, 26% and 54% belonged to age categories of over 61 years, between 36 to 45 years and between 46 to 60 years respectively. Education level of the respondents is an important factor which affects the decision making process. Results explicated that, almost all the respondents (100%) have attained formal education where higher percentage (45%) of respondents did schooling up to General Certificate of Education (GCE) ordinary level (grade 11). Moreover, 25% of respondents did schooling up to grade five and 21% did schooling up

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to grade ten while the least number of respondents (9%) completed education up to advanced level. Thus their response is comparatively matured and reliable to be taken into the actions in the watershed management programme particularly in water quality improvement.

3.7 Views of the Farming Community on the Ecosystem Components of the TCS

Study investigated the current situation of different features of *Thirappane* cascade system and the respondents' awareness about the importance of those features. Majority of the respondents reported that the unique ecological features are still visible around the small tank system. Of those features drainage canal (*Kiul Ela*), Earthen embarkment/dam (*Wa kanda*), (upland crops cultivation area, *Chena*), hamlets (*Gan Goda*), downstream wind barrier located in between the sluice and paddy *Katta Kaduwa* (observed in few tanks) , Paddy fields (*Keth yaya*) , spillway (*Pitawana*), land sluice (*Goda Sorowwa*) and mud sluice (*Mada Soruwwa*) are still observable while (small pond for trapping sediments) *Godawala* and earthen small embankment to prevent entering sediments (*Iswatiya*) are evident up to some extent in the small tank cascade system. But, the land strip around the hamlet for protection (*tisbamme*), trees (specially *Madhuka longifolia*) over the drainage canals, trees over *Katta Kaduwa* are not observable today. Transect work observed that those features are in highly degraded conditions. Further, many of the respondents (81%) highlighted the importance of restoration of these unique features of cascade system.

Table 6. Awareness and willingness to rehabilitate the tank cascade system of *Thirappane*

	Questions related to awareness and willingness to rehabilitate tank ecosystem components	Positive Response of the respondent
1	Awareness that the farmers are living in a tank cascade system and are taking water from the TCS	94%
2	Awareness that each tank has its own ecosystem components and they have specific role in improving the water quality and minimizing the siltation	64%
3	Awareness that present status of the ecosystem components are in degraded status	60%
4	Farmers willingness on the possibility of tank ecosystem components to be rehabilitated as in the past	81%
5	Farmers willingness to supply labour to rehabilitate the tank ecosystem components	54%

According to the views of the respondents major factors that affected the water and soil pollution of the *Thirappane* cascade system were the use of chemical fertilizer and agrochemicals for crop cultivation, soil erosion, movement of buffaloes and cattle, elephants crossing the tank bunds and inadequate repairs and management of the water cannel system. Water quality survey also observed the higher levels of sediments in terms of turbidity and accumulation of *nutrients (NO_3^-, $PO43^-$)*, in water. Further, Table 7 displays measures that can be taken to minimize the pollution of the eco-system of the *Thirappane* cascade system.

People in the area believe that proper awareness programme on the importance of ecosystem components of the TCS is one of the main measure to minimize impairment of water in TCS. As an alternative, they wanted to restore the forest in the upper catchment area of each small tank which is now degraded substantially. Respondents in the area accept that minimization of the use of agrochemicals and synthetic fertilizer for crop cultivation will lead to improving the water quality. Around 13 % of the responded farmers also wanted to rehabilitate the ecosystem components of the TCS in order to improve the water quality status of the TCS. Use of appropriate farm soil conservation methods is also believed to be a measure to enhance the water quality status while combating deforestation in the TCS is the least ranked method selected by the respondents.

Table 7. Measures to minimize the pollution of *Thirappane* cascade system

Rank	Measure to minimize the pollution	Response of the respondent
1	Awareness programme for farmers about the importance of conservation of *Thirappane* tank cascade system	29%
2	Reforestation of upper catchment area of small tanks of the cascade system	25%
3	Minimize the use of agrochemicals and synthetic fertilizer for crop cultivation	20%
4	Rehabilitation of features of tank cascade system according to the standards	13%
5	Use of proper conservation methods (ridges, drainages etc.)	9%
6	Minimize the deforestation of tank area	5%

Table 8. Factors affecting on community participation decision to conserve *Thirappane* tank cascade system

Variable	Measurements	Pr>Chisq	Estimate	Odd ratio
Educational level of the respondent	Up to grade 5	0.95	5.865	<0.001
	Up to grade 10	0.95	-5.2781	<0.001
	Up to grade O/L	0.96	-4.2565	<0.001
	Up to grade A/L	0.97	6.895	1.000
Drinking water source	Tap water	0.94	-8.794	<0.001
	Filtered water	0.98	2.931	1.000

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Variable	Measurements	Pr>Chisq	Estimate	Odd ratio
	Well water	0.99	2.931	1.000
Satisfaction about the quality of drinking water source	Satisfied Vs. not satisfied	0.006*	-2.40	<0.001
Number of years living in the area	< 5 years	0.99	-5.595	<0.001
	< 10 years	0.87	-5.910	<0.001
	< 20 years	0.95	5.75	1.000
Land extent	Acres	0.98	0.0058	1.000
Annual income	Rupees	0.08**	6.47	1.000
Presence of features of cascade system	Yes	0.01*	0.947	6.563
Awareness about cascade system	Yes	0.07**	1.14	9.778

*significant at 5% significant level and **significant at 10% significant level

Table 8 shows the results of logistic regression estimates of the factors affecting the participation decision for the conservation of *Thirappane* tank cascade system. According to the results, satisfaction about the quality of drinking water (p<0.05), presence of ecosystem features of tank cascade system (p<0.05), annual income of respondents (p<0.1) and awareness about the tank cascade system (p<0.1) significantly influenced the participation decision of the community for the rehabilitation of TCS.

Results revealed that, when the community people lost their satisfaction about the quality of drinking water (OR=<0.001) many of the respondents tend to change their decision to participate in tank cascade system conservation. Presence of features of ancient tank cascade system (OR=6.563) affected positively to change the respondents' decision to participate in conservation programmes. Further, increase in annual income of respondents (OR=1.00) results in many of the non-participants to participate in cascade conservation. Meanwhile, more awareness about the importance of cascade system (OR= l.00) leads to change non-participants decision.

The social survey highlighted the positive attitudes of the people towards conservation of *Thrappane* TCS and their willingness to participate in watershed management programme in order to make the water safe for drinking as their forefathers used. The information collected under this study is very vital to the scientific community, government officers and farmers themselves in protecting the TCS in Sri Lanka. Similar studies shall be continued as a routine procedure in other TCS too to understand the reality and harness the water at a lesser cost as practiced by the early Sri Lankans.

This study could not consider the microbiological properties of water and could not test the water quality parameters for the 2020 *Maha* as planned due to Corona pandemic situation. However, this study became the ground for the formulating of a cascade management plan with the support of the community. This study shall be an example and an eye opener to the country to formulate sustainable watershed management plan.

4. Conclusions

Health of the *Thirappane* TCS in terms of water quality of *Maha* cropping season was tested and the mean status of some drinking water quality parameters such as turbidity, free NH_3 , COD, Pb and Cr exceeded the SLS 614 (2013). Other than that, maximum values recorded for EC, total alkalinity, total phosphate, COD, TDS, Mg, Cu, Cr, Fe, Mn and Zn of the *Thirappane* TCS were higher than the stipulated standard values for potable water. Moreover, calculated DWQI of tanks water of TCS was not up to the suitable level to use the water as potable water. However, most of the irrigation water quality parameters tested and IWQI guarantee that the TCS water is suitable for irrigation of any crops which would not deteriorate the yield and the soil properties. This study further concluded that awareness programme on the importance of ecosystem components of the TCS would help to conserve the TCS and clearly showed the willingness to participate for the rehabilitation work of the ecosystem components by the stakeholders in improving the water quality status. However, the presence of ecosystem features of tank cascade system, annual income of the respondents, satisfaction of the quality of drinking water, and the awareness about the tank cascade system significantly influenced the participatory decisions of the community on the rehabilitation of TCS.

Data Availability

Whenever needed, the data can be shared.

Conflicts of Interest

No conflicts of interest among authors.

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