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Management, Mitigation and Recovery

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ALEJANDRO ZOHN'S MATHEMATICAL DESIGN PROCESS, APPROACH THROUGH THREE-DIMENSIONAL ANALYSIS

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ABSTRACT
Alejandro Zohn (1930–2000) was one of the most important architects in the second half of 20th century in Guadalajara, Jalisco. Their work in public space is linked to the most important spaces in the city, although the studies about him have left most of his process and architectural and spatial comprehension. With well-known teachers and references like Mathias Goeritz, Félix Candela or Eduardo Torroja, Alejandro developed a design process based on arithmetic compositions using geometric pure volumes, in most of the cases in concrete. Alejandro Zohn's commitment with mathematical and geometric purity relates him with nature and its rules, also depending on mathematics and fractal growth, what leads his designs to a good public appreciation although the state of conservation is quite disturbing in some of the cases due to administration neglect.

In the case of the works for public spaces studied in this paper, Alejandro Zohn generated a fractal growth in order to balance the volumes, weights and dimensions, with the use of hyperbolic paraboloid to lead the structural stress of the demanding forms to the floor with the highest lightness possible

In order to achieve a full vision of this growth and balance, this work focuses in showing the volumes used in the composition transforming them from the two usual dimension of floor and elevation to three-dimensional volumes, showing the conceptual complexity of this two apparently simple shapes.
Keywords: fractal growth, functional structures, geometry, hyperbolic paraboloids, monumentalism, nature-related forms

1 INTRODUCTION

On the second third of 20th century in Guadalajara, Mexico, architecture production experienced an explosion as it was never seen before, not only about the amount of production, with the uncontrolled expansion of the city, but about its quality and important projects which nowadays are still a referent in the city.

Well-known architects like Luis Barragán, Mathias Goeritz or Ignacio Díaz Morales can be studied, in order to understand nowadays architecture references in the city. But in order to understand the public spaces of the city, and how they arrived to achieve their moment of splendour and later downfall is needed to analyse the figure and works of Alejandro Zohn (1930–2000) [1]. As he was the architect who defined successfully most of the big public spaces such as Agua Azul Park, López Mateos sport complex, Liberty Market, 14th February sport complex and park, or the pedestrian bridges in the Colomos Park, which still keep part of their preceding greatness in the city.

2 ALEJANDRO ZOHN'S CAREER

2.1 Childhood and studies

Although Alejandro Zohn Rosenthal was born in Austria, on 1930, he moved to Mexico in his childhood, and settled with his mother, who was chemist, and his father, who was accountant, in the town of Tlaquepaque. With a childhood marked by science and mathematics, he

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studied civil engineering in the Universidad de Guadalajara, but when architecture studies were available in the same university, he decided to study both at the same time, ending Civil Engineering degree on 1955 [2] and the architecture degree, according to the yearbook of the University of Guadalajara [3] in 1959. Becoming this double formation in the foundation of its later architecture and spatial comprehension both in buildings and public space projects.

In Alejandro Zohn's double formation stand out Dr. Marian Goeritz [4] her married name, real Marianne Gast, photographer and writer [5], architect Jaime Castiello Camarena [6] influenced by the modern movement, architect Ignacio Díaz Morales [7] precursor of regionalist architecture [8], Prof. Domingo Lobato [9], composer, organist and teacher [10], Ing. Francisco González Rojo [11] writer, film scriptwriter and ethnologist [12], Architect Eric Coufal [13] work inspired by the Mexican tradition, specifically in crafts, Dr. Manuel Herrero Morales [14] Mathematician professor from Spain [15], Mr. José Arriola Adame [16] and Dr. Mathias Goeritz [17] architect, sculptor, painter, poet and art historian [18], this one, played a key role from the beginning of Zohn's training, being the reason why he decided to enter the architectural career: 'I kept studying engineering, and at that time a series of people came to what was the school of architecture, among them Mathias Goeritz. I met him casually on one of the visits, and since I had some time between engineering classes, I got into some of his classes and I liked them a lot. I think it was because of Mathias that I got into architecture' [19].

Special consideration in Alejandro Zohn's education was the Spanish architect Félix Candela, as a usual guest teacher in Universidad de Guadalajara [20] after his exile after Spanish civil war [21], even more when the two pieces analysed in this investigation are shell structures in concrete, in which area Félix Candela is the most recognized pioneer.

2.2 Alejandro Zohn design bases

In the collective consciousness of Guadalajara, Alejandro Zohn works have a special place, even unknowing to the author who create them, as the most iconic public spaces in the city growth in the second half of past century have their footprint. For architects, urban and history interested Alejandro Zohn is an essential figure for understanding nowadays Guadalajara. 'Zohn represents, maybe as any other member of his generation – and all the other generations graduated from Diaz Morales' school (…), a living and literal synthesis of the two main lines that embody the best architecture that has ever been built in this region. On one side, the rigor of the number and the method, of the economy and the efficiency. On the other, the flight of imagination and the cultural background of a rich and contradictory past' [22].

These two academic lines of the university, strengthen in Alejandro Zohn by the previously explained duplicity of studies, make the base for all his works, where the use of an extremely precise mathematic definition of the projects with the adoption of natural references, also defined by mathematics, lead the configuration and expressivity of the architectural object.

Focusing on the projects for public spaces, the answer to the project incorporates the public dimension, and the use of paraboloid, hyperbolic paraboloid and other mathematic figures allow Alejandro Zohn to create the most expressive shapes and spaces in the moment when this kind of geometries were in doubt about their functionality.

3 SELECTED WORKS

For the analyses in this work, the two of the most important pieces in public space made by Alejandro Zohn were chosen, in first place the Acoustic shell inside the Agua Azul Park,

where he developed some other interesting pieces like the pedestrian bridge which runs above an avenue. And, in second place, the main entrance of a whole project of him, the López Mateos Sport Complex.

Both pieces, the most relevant parts of whole projects, have the astonishing presence that Alejandro Zohn choose to the most iconic places of the projects. In first place, and outdoor auditorium, where the mathematical form of hyperbolic paraboloid is used, in addition of structural lightness and material efficiency, as the responsible of spreading the sound of the different performances in the most appropriate way. In the case of the entrance to the Sports Complex, the shape is far more intricate, as Alejandro Zohn combines precisely five main hyperbolic paraboloids in one unique piece with the shape of a cross.

Also, in these two elements, the commitment of Alejandro Zohn in all his curve shaped works with the mathematics behind the geometry is remarkable, as he does not modifies the geometry of the hyperbolic paraboloid in any sense, as well as he delimitates all the shapes with straight lines, which is what hyperbolic paraboloid is generated from.

3.1 Acoustic shell in Agua Azul Park, Guadalajara, Jalisco

In 1959, Alejandro Zohn is entrusted to design an acoustic shell for the most important urban space on that time, while he was still a graduate from his civil engineering studies and still had not graduated in his architecture studies [23].

Geometrically, the shell is the central portion of the hyperbolic paraboloid Alejandro Zohn uses to distribute the sound far and wide on the audience pit. In this case, while the hyperbolic

Figure 1: Acoustic shell in Agua Azul Park (Zohn's archive).

paraboloid is used to take advantage of its internal structural strength, the length of the two elevated corners is different, generating the centre of mass centre is displaced to the acting area. This imbalance is solved by Alejandro Zohn with the wide stone pilasters on both sides, gathering the centre of mass position within their area.

3.2 Main access in López Mateos sport complex, Guadalajara, Jalisco

In the same year, Alejandro Zohn designs the López Mateos sport complex, in which settles for the entrance an eight corners element joining five different hyperbolic paraboloids, one in the centre and four for the wings with four more paraboloids for the junction. In addition, for reinforcing forces distribution between the two biggest wings and reducing the high stress generated in the junctions of the paraboloids, Alejandro Zohn generates a second layer of hyperbolic paraboloids above the first one, contributing to the momentum of the long cantilevers generated.

Thus, in this more complex piece, Alejandro Zohn shows his ability to compensate the weights in four directions from the centre paraboloid, while using three different lengths and heights on the wings. Being possible through the use of the pure mathematics shapes and graphics for the perfect union of the consecutive paraboloids.

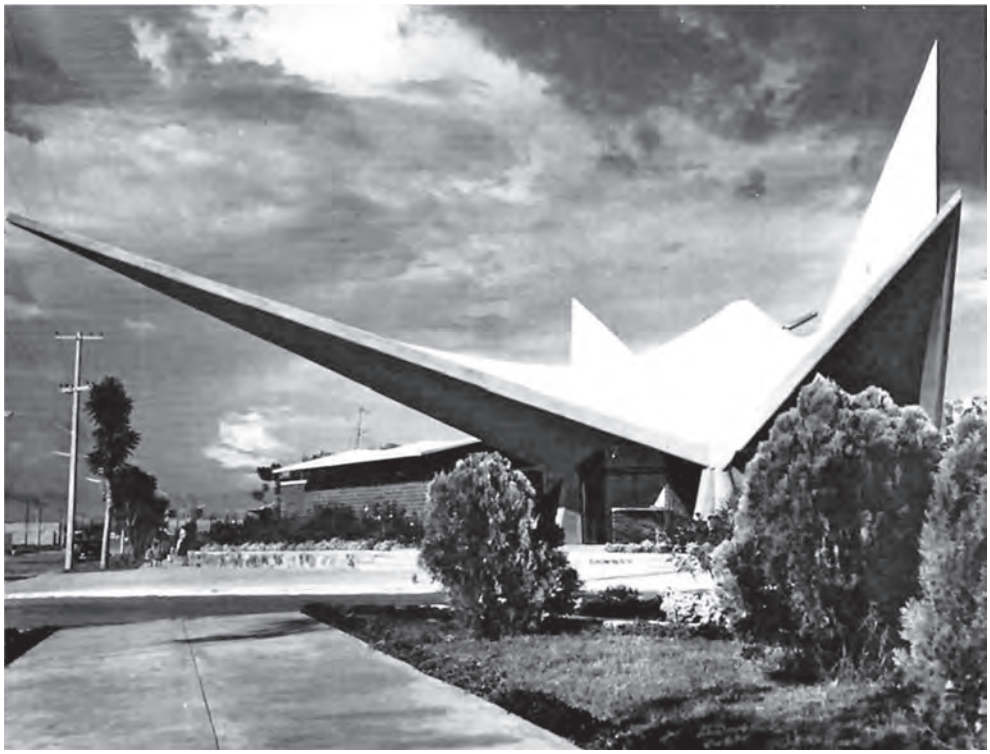

Figure 2: Main access in López Mateos sports complex (Zohn's archive).

4 METHODOLOGY

The relationship between geometry, nature and public space appreciation is the connectors for the mathematical geometry used by Alejandro Zohn. With the aim to create impressive shapes and forms that seem to challenge the laws of physics, he incorporated the forms of nature into his designs, positioning him as an advanced to nowadays used concepts of biophilia and fractal nature inspired designs. The junction of this valued concepts, where building environment is understood as an extension of the humans and, therefore, more appreciated in a subconscious level [25] and linked to natural processes carried out in the basic, cellular, and chemical nature [26] seems to be related to the esteem by citizenship.

The methodology applied is based on geometry and mathematics using a three-dimensional analysis of the golden ratio through a three-dimensional modelling of the cubes which define Alejandro Zohn's projects. And, contrasting it with the results of public appreciation of them in public space according to the results of a survey carried out in the city of Guadalajara [24] shows public appreciation of the projects from Alejandro Zohn analysed in the current study in comparison with other projects of similar characteristics where other examples do not present this kind of sensitivity to nature. Particularly, in the results to the question of which shape seems more attractive to surveyed people, as can be seen in Fig. 3, where Alejandro Zohn works are coloured blue. This survey was answered by 117 people in order to fulfil a 95% trust and 15% margin of error with the population established around the two parks where the urban elements selected are 41,455.

Alejandro Zohn's acoustic design is preferred with a 33.3%, but close to other two options. It can be interpreted as most of the shells have designs that can be appreciated by the society. Nevertheless is important to notice than comparing with the next two options, Zohn's construction is by far the one in worst maintenance condition, what must lead to a thought about the care of local architecture referents in our cities.

For the next element studied, the impressiveness of the form explained of Zohn's design for Sport Complex' main access in López Mateos is shown with the biggest difference in voting, as other entrances for parks in the city have more sober and rectangular designs, what differences it notoriously from the others, even being in one of the least glamourous areas of the city, while in other photographs were entrances of more appreciated, more cared and visited parks, located in wealthier neighbourhoods.

Figure 3: Survey results to question 'Which shape is more attractive to you?'.

5 GEOMETRIC ANALYSIS, TWO- AND THREE-DIMENSIONAL

In order to understand the geometry of buildings, specially related to analysis of geometry linked to golden ratio, these studies have been made in floor and elevation plans, where golden ratio is drawn on the plan showing the harmony of the designs and their internal relationships.

Nevertheless, nowadays way of working, in which designs are predominantly developed in three dimensions through the whole process of designing, from the general conception to the details of engineering thanks to technological advances brings other questions to be solved.

The one searched to be attended in this paper is how far the two-dimensional geometric analysis have left aside the real perception of the architectural object by the users, as their inherent three-dimensional reality can modify the recognition of proportions. So that realizing that both analysis, floor and elevation, need to work together specially in those cases where the elements studied are far from being flat, as the usual analysis of flat facades of a church front. In these cases, the visual distortion of the observer added to the dimensions and different planes between the different volumetric elements generates the doubt of the convenient appreciation of the proportion understood and obtained in two-dimensional analysis.

For this reason, in the present paper, a three-dimensional analysis is made for two pieces selected of Alejandro Zohn, developing a previous work of two-dimensional analysis [24] based on golden ratio (φ = 1:1.61803…) with the result of Figs. 4–7, respectively. Evolving the comprehension of Alejandro Zohn's pieces with the aggregation of proportions in a unique three-dimensional model.

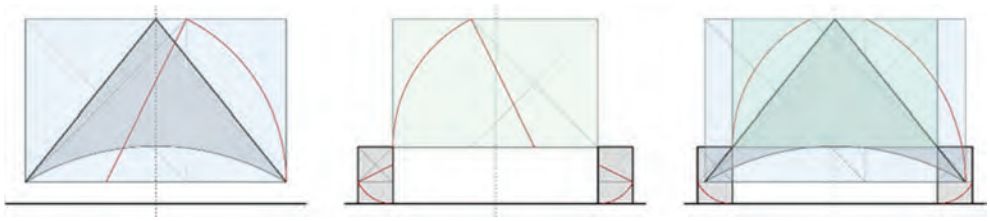

Figure 4: Acoustic shell, frontal view, geometric analysis.

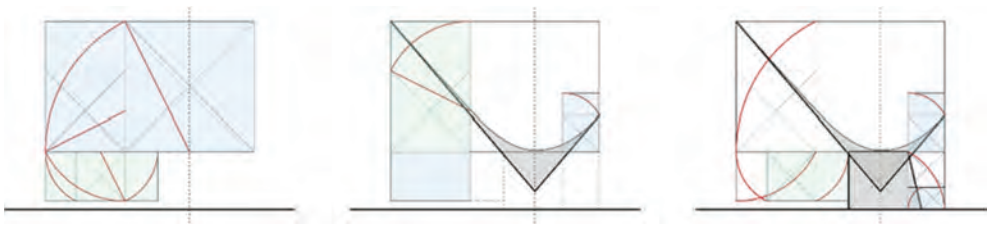

Figure 5: Acoustic shell, side view, geometric analysis.

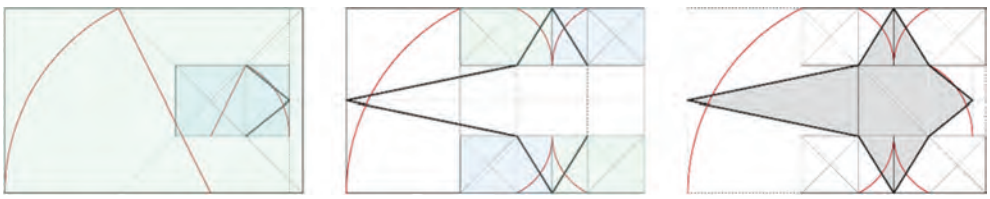

Figure 6: Access, floorplan, geometric analysis.

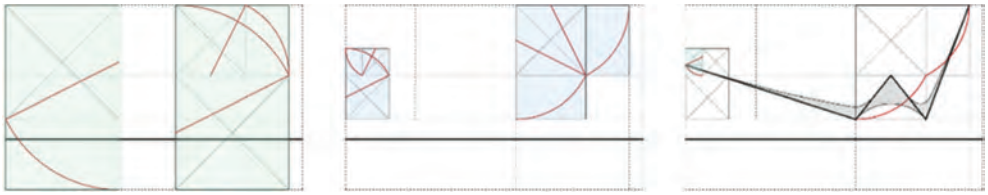

Figure 7: Access, sideview, geometric analysis.

6 THREE-DIMENSIONAL UNDERSTANDING OF ALEJANDRO ZOHN'S WORKS

The starting point in the analysis in both cases is the biggest cuboid related to the hyperbolic paraboloid concrete shell with dimensions of 1:1:ϕ (height:length:depth). From which succeeding reductions point out the position of each point that confines the hyperbolic paraboloid.

6.1 Acoustic shell in Agua Azul Park, Guadalajara, Jalisco

In the beginning for the analysis of the acoustic shell, composition starts with a basic orthohedron with the golden ratio proportion in length, the same direction as the frontal cantilever, as can be seen in the elevation analysis, Fig. 5. This initial cuboid defines the top corner of the shell, while with two golden ratio divisions the main horizontal square for the shell is delimited and the smallest cube will be the beginning for the definition of the height and position for pilasters.

From the smallest cube, located in front corners, an extension is grown by golden ratio, from there a new division and extension marks off the position for the pilasters.

Therefore, the next golden ratio for pilasters is defined as well as its position, also determined by the second golden ratio division of itself. In upper direction, the same cuboid of the pilasters but inside the initial orthohedron positions the exact point for the top corner of the shell in the posterior wing.

Also, in figure 10 can be seen that, although in two-dimensional interpretation the frontal proportion of the main shell generates and own golden ratio rectangle, when working with the three dimensions together, the exact point of the low corner of the shell can be found with the third split developed in the cuboid related to define the two stone pilasters on the sides. What is far more exact and offers us a new understanding not only about the proportions between pieces that could be seen more unconnected in two dimensions, but about the relation of these corners with the pilasters and the centre of mass located in the area structurally controlled by the pilasters. What shows us about the real distribution of forces between the shell and pilasters, and the relation of the direction of the shell in its lower edge and the tilt of the exterior edge of the pilasters, which is also defined by the golden ratio.

In sum, the correlative evolution of the cuboids from an initial simple form shows in this project how the dimensions are related between and with a whole, obtaining the aesthetic, functional and structural balance pursued and, as said, appreciated by the observers.

6.2 Main access in López Mateos sport complex, Guadalajara, Jalisco

The case of the entrance to López Mateo's Sports Complex the shape is fully composed inside a main orthohedron defined by golden ratio in both long sides and a square face.

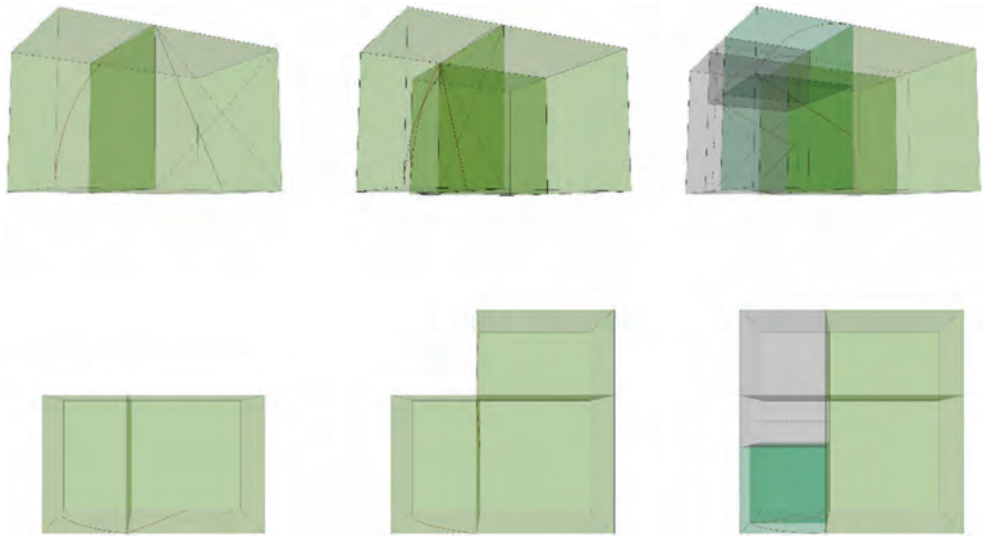

Figure 8: Initial three golden ratio evolutions for the acoustic shell.

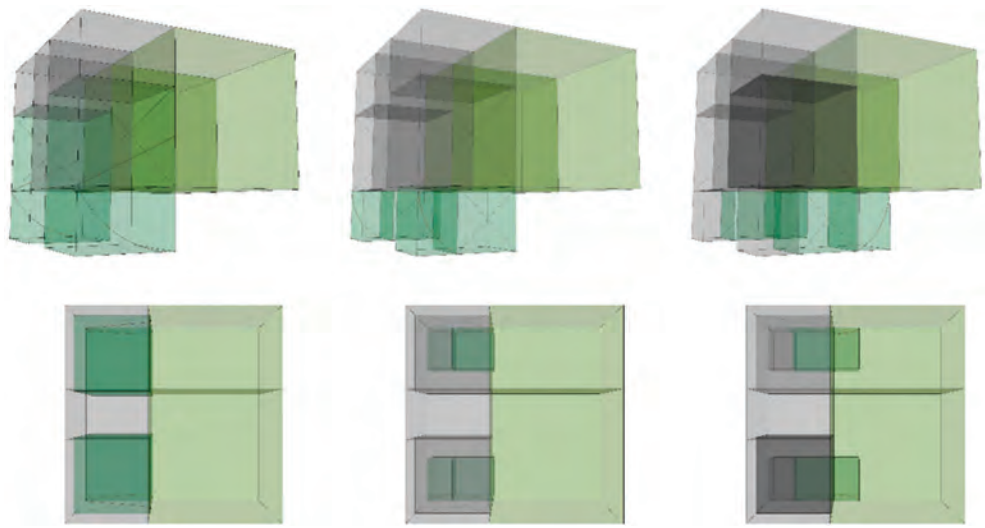

Figure 9: Halfway golden ratio evolutions for the acoustic shell.

Growth in its evolution is developed along four different geometric series of Fibonacci's section surrounding a squared central space, where the entrance is located. This central space gathers the different forces from the four directions locating the centre of mass and conducting the forces to four only supports under the four central delimiting points of the group of hyperbolic paraboloids. This way the whole piece is balanced structural and aesthetically, as well as functionally.

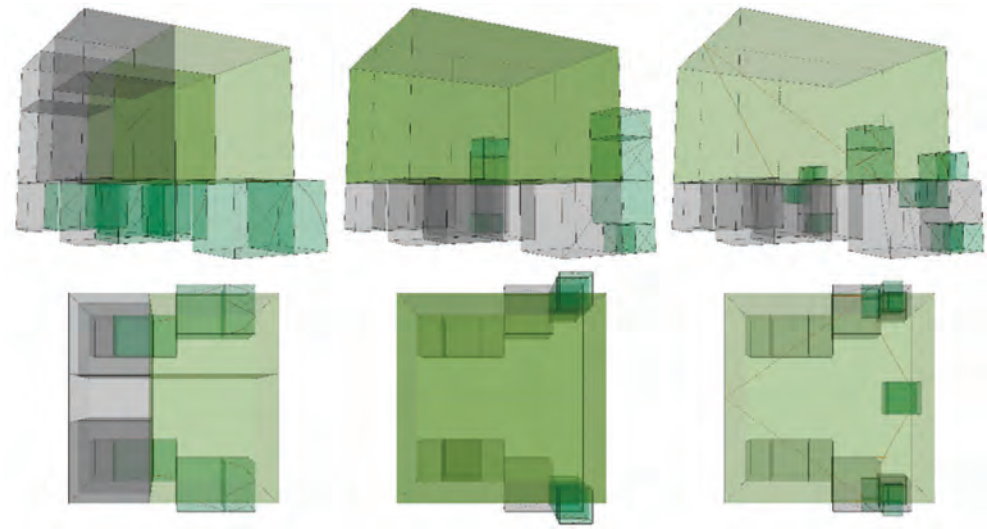

Figure 10: Final golden ratio evolutions for the acoustic shell.

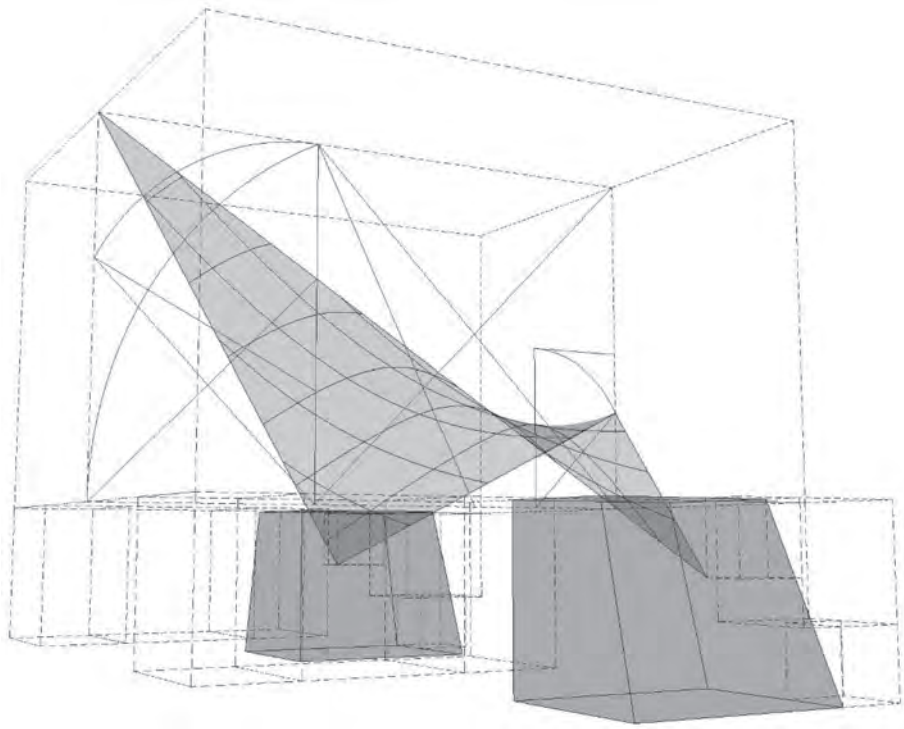

Figure 11: Summary three-dimensional golden ratio configuration for the acoustic shell.

Initially, the big golden rated cuboid is divided three times along the edges of the main cuboid by golden ratio in order to obtain the dimension of the central cube, from where the four wings of the shape will expand. This case has more complex evolution than the acoustic shell, therefore Figs. 12–15 are used to display the most representative moments in the evolution of the analysis, so some of the steps do not appear because of space saving reasons.

From the golden ratio cuboids around the central space, as can be seen in lower right position of figure 12, extracting the cube and expanding by golden ratio horizontally, both lateral wings are defined in their three points, as shown in first pair of images in Fig. 13. Coming back to the main central cuboid over the entrance, expanding it also horizontally top corner is in the centre

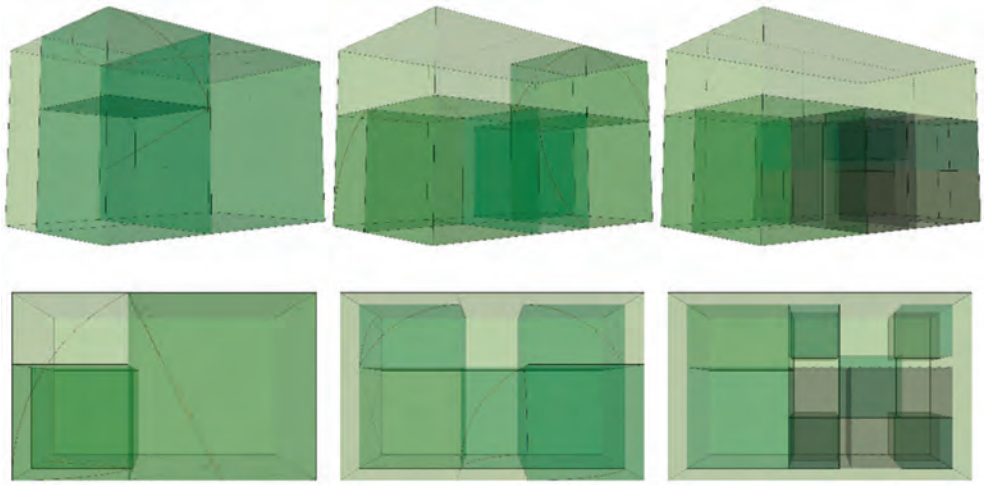

Figure 12: Initial selection of golden ratio evolutions for the access to sport complex.

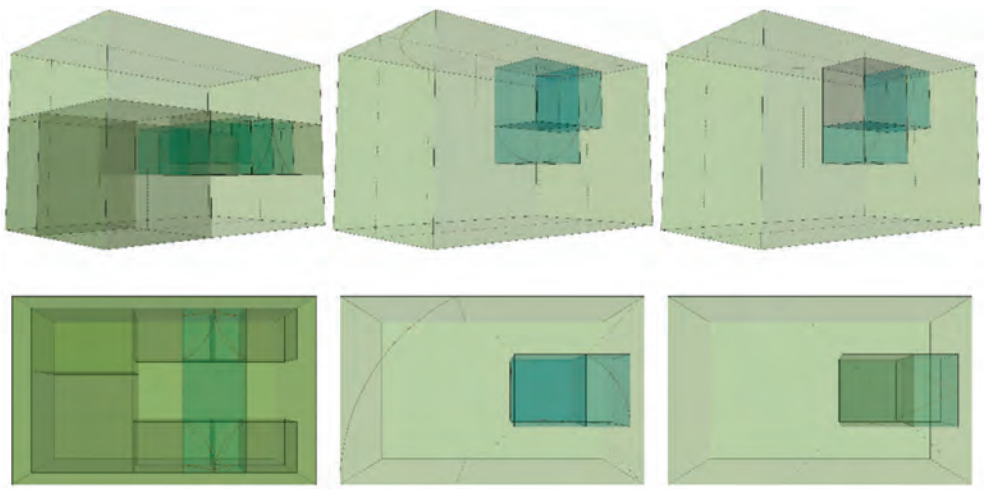

Figure 13: Second selection of golden ratio evolutions for the access to sport complex.

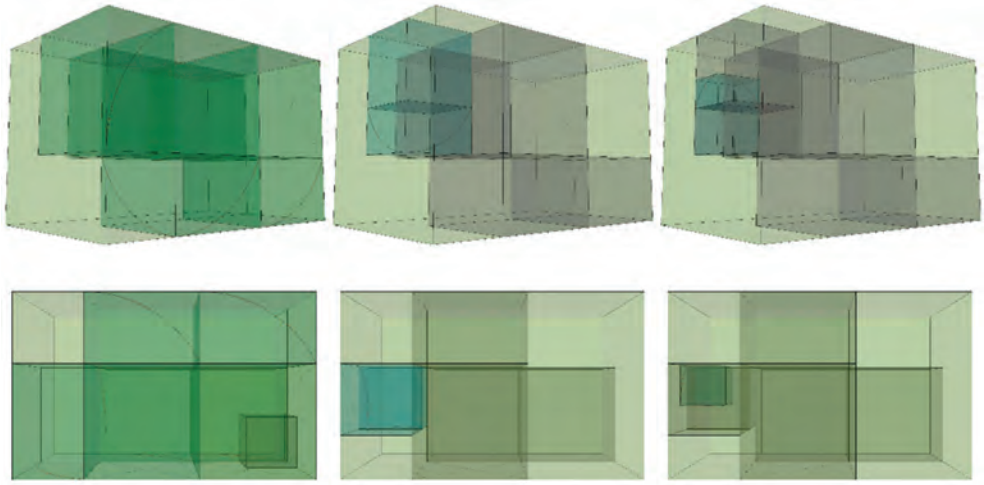

Figure 14: Third selection of golden ratio evolutions for the access to sport complex.

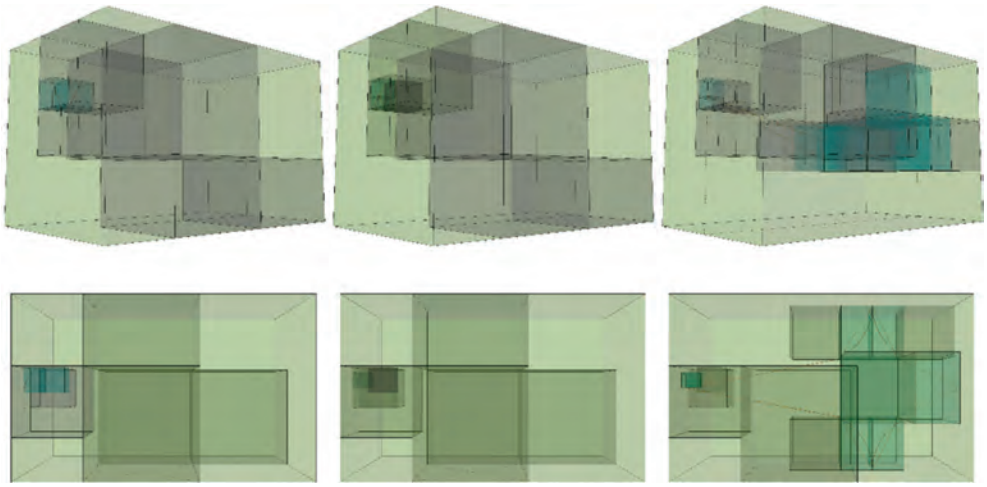

Figure 15: Final selection of golden ratio evolutions for the access to sport complex.

of the horizontal golden rated volume while on the vertical also golden rated volume are located in the two lower corners.

The final dot left is the one which is more representative in the structural element, as the final point of the cantilever above the sidewalk. To achieve its position, the first vertical division of the initial cuboid is needed to go back, as seen in the first pair of images in Fig. 14. Then, in its horizontal golden ratio, three internal and successive golden ratio evolutions set the height of the last point in the cantilever.

In sum, an important amount of iterations have been developed for this case, accordingly with the more complex configuration of the element, where gravitational forces in four directions are guided to four central points which connects the light shape with the floor.

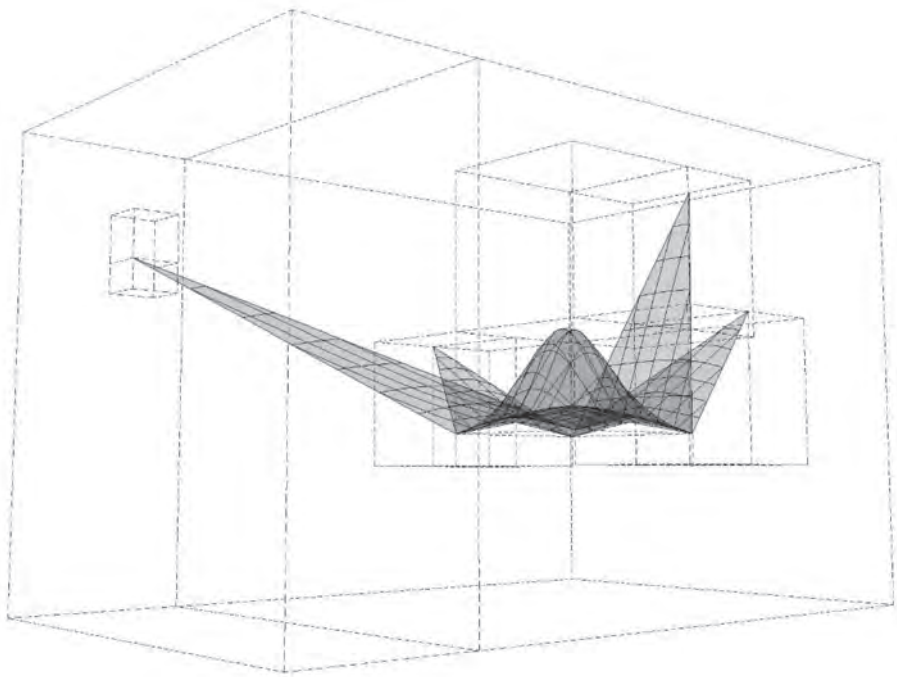

Figure 16: Highlighted three-dimensional golden ratio volumes for the definition of the access to sport complex.

7 CONCLUSIONS

After the three-dimensional analysis of the two pieces of Alejandro Zohn, and regarding the previous results developed in floor and elevation plan, it is important to accept the limitations of two-dimensional examination when studying volumetric pieces proportions, as the dissertation of volumetric pieces has made possible to spot several new correlations in both examples. From which results can be understood far more complex mathematical and perceptual associations can be found when working with models and volumetric geometries.

This reflexion also opens the path to a further revision of many analysis performed in two dimensions, not with the intention to expose any potential errors or faults in the investigation, but with the purpose of finding relations and proportions that have remained hidden until now. So, the appreciation and understanding of the buildings can be enriched and design process associated can be reinterpreted.

Having a new approach to understand proportions and volumetric relations, in which pedestrian observers are included as the key point of the three-dimensional understanding is related with how watchers perceive and valuate the interest of built environment. In this way, three-dimensional studies are more suitable to understand how design process should propose the aesthetic of public spaces design and proportions, taking into account for example the distance of the observer, the dimension of the object designed and the complexity of the object.

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COMPARATIVE ECOSYSTEM ANALYSIS OF URBAN PONDS: IMPLICATIONS FOR SYNERGISTIC BENEFITS AND POTENTIAL TRADE-OFFS RESULTING FROM RETROFITTING OF GREEN ROOFS IN THEIR CATCHMENTS

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ABSTRACT
This paper provides a summary of ecological functioning, biodiversity and water chemistry of two sustainable drainage systems (SuDS) ponds, and compares the level of ecosystem services with those attainable by retrofitting green roofs (GRs) in the ponds' catchments. These study sites are characterised by relatively high diversity of habitats, including aquatic, mesic and terrestrial; the importance of the latter is highlighted using the analysis of vascular plants and calcicolous lichens. Both SuDS sites provide valuable multiple benefits related to the enhancement of local biodiversity, water quality improvement and alleviation of flood risk, and the retrofitting of GRs would further enhance flood resilience and biodiversity of the area. However, there might be potentially negative effects on the runoff water quality and hydrobiological community composition of the receiving ponds. Changes in the runoff chemistry combined with the decreases in flush rate of high-flow events would increase the risk of cyanobacterial dominance during late summer and autumn. Such trade-offs should be carefully considered in planning any practical actions. This study elucidates indirect effects by following the methodological framework of comparative ecosystem analysis, which will be of use for any research and applications considering implementation of complex nature-based solutions (NBS), including those within the context of sustainable development of blue-green cities (BGC).
Keywords: blue-green infrastructure, community structure, CTEA, hydrological modelling, indirect effects, mesofauna, newts, plankton, runoff chemistry, terrestrial flora, fungi, urban pollution.

1 INTRODUCTION

Sustainable drainage systems (SuDS) are an important component of modern green and blue-green infrastructure (GI/BGI), and are indispensable for sustainable urban development [1, 2]. A well-developed GI/BGI network provides a number of important ecosystem services including, for example, flood risk reduction, water quality improvement, biodiversity enhancement, recreation capacity, among others [3–6].

Green roofs (GRs) and urban stormwater ponds are the types of SuDS whose multiple benefits have received a fair amount of attention from researchers and practitioners [7–12]. These BGI components have been increasingly used as part of nature-based solutions (NBS) both in the UK and worldwide. However, the estimation of overall benefits provided by a combination of BGI components is not straightforward, and the interactions and trade-offs between various SuDS assets remain under-investigated.

Here, we address this research gap by investigating what would happen to the ecosystem services related to hydrology, water quality and biodiversity of SuDS ponds following the retrofitting of GRs on buildings situated in the ponds' catchments. These research questions are investigated for two case study sites whose functioning has previously been discussed

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[13] in relation to the 'No GRs' scenario (i.e. the current situation). This paper builds on the previously published materials and reports on further details of the water chemistry and the new results of calcicolous lichen surveying, which highlights the importance of the terrestrial habitat provided by engineered structures. It provides a summary of the baseline conditions; ecological patterns and the current level of ecosystem services are compared with those which may potentially result from the introduction of different types of GRs. In particular, specific attention is devoted to the indirect effects resulting from complex interactions among hydrology, water chemistry and the characteristics of the biological community [14, 15].

2 HYDROLOGY

The maps of the Juniper Green and Oxgangs ponds catchments are presented in Figs. 1 and 2 respectively. They are located south-west of central Edinburgh within the urban environment and about 4 km apart. As can be seen in these figures, the area covered by buildings appears to be relatively larger in the Juniper Green Catchment (35.5%) than in the Oxgangs catchment (25.6%). The coverage of other impermeable areas (e.g. pavements) is similar (59.7% and 61.1% at Juniper Green and Oxgangs respectively), whilst there is considerably more green space at Oxgangs (13.3%) compared to Juniper Green (4.8%).

It should be noted that the catchment boundaries depicted in Figs. 1 and 2 (and subsequently used for the analysis) were first delineated using LIDAR data and then adjusted in line with the drainage schemes obtained from Scottish Water. The latter information helped to allocate the specific buildings, and even their parts, to the ponds' catchments. For example, according the Scottish Water drainage plans, runoff from the community centre located immediately west of the Oxgangs pond does not drain to the pond (Fig. 2). Also, there is a long building at

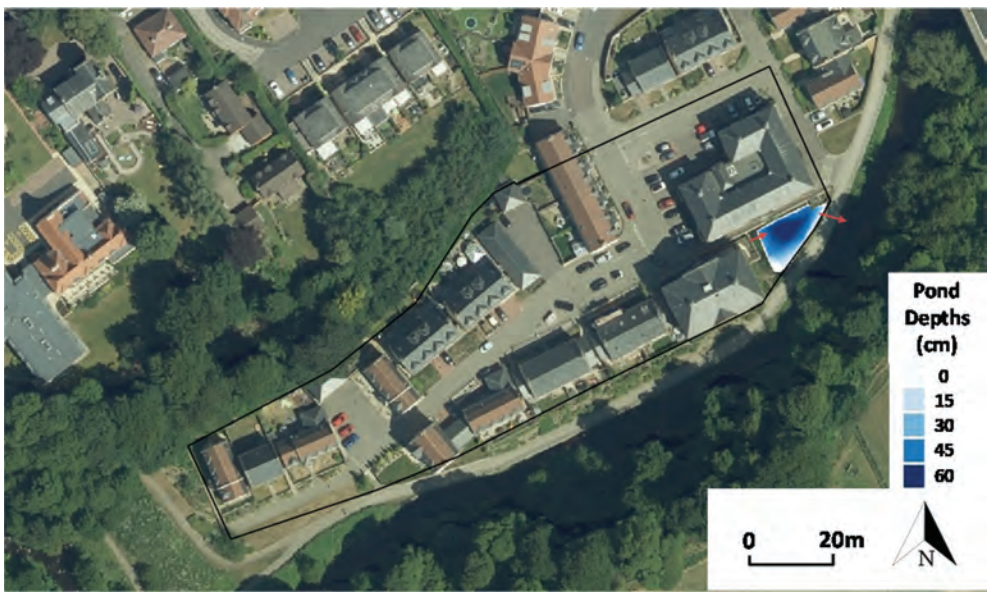

Figure 1: Catchment of the Juniper Green pond. The surface area of the pond is 220 m^2. The inlet to the pond and outlet from the pond are shown as red arrows. The black line shows the catchment boundary for water that drains into the pond which has an area of 7,900 m^2.

Figure 2: Catchment of the Oxgangs pond. The surface area of the pond is 1,750 m^2. The two inlets to the pond and outlet from the pond are shown as red arrows. The black line shows the catchment boundary for water that drains into the pond which has an area of 30,800 m^2.

the north of the Juniper Green catchment which only partly drains to the pond (Fig. 1); runoff from houses numbered 12–14 drains to the pond, whilst runoff from the house numbered 11 is diverted for drainage elsewhere.

Hydrological modelling of the ponds' catchments was carried out using SHETRAN, whilst hydrodynamic simulations of extreme events were performed using CityCAT. Both are well-established modelling analysis tools developed by Newcastle University [16–19]. For simulations involving green roofs scenarios, both models were adapted by adding a green layer over the areas covered by buildings. Two scenarios were considered: one with a 10-cm deep soil and one with a 20-cm deep soil. As CityCAT only considers events this is a simple storage term. In SHETRAN, parameters related to soil conductivity and evapotranspiration were adjusted to reproduce a slow release of water from saturated green roofs, following an exponential decay curve and decreasing to negligible values over 10 days. We also assumed a 10% residual water content which is not available for drainage from a green roof but is subject to gradual evaporation. This is a conservative estimate reflecting the uncertainty of slope and construction details. Further details on the catchments' properties and description of the software used are documented in our previous publication [13].

2.1 Pond discharge and water residence times

Figure 3 presents the estimated water discharges from both ponds under a range of scenarios. It is evident that although the retrofitting of GRs would result in the attenuation of discharge the differences between different scenarios are rather small. It should be noted, however, that these results are for daily discharge, and the instantaneous differences are expected to

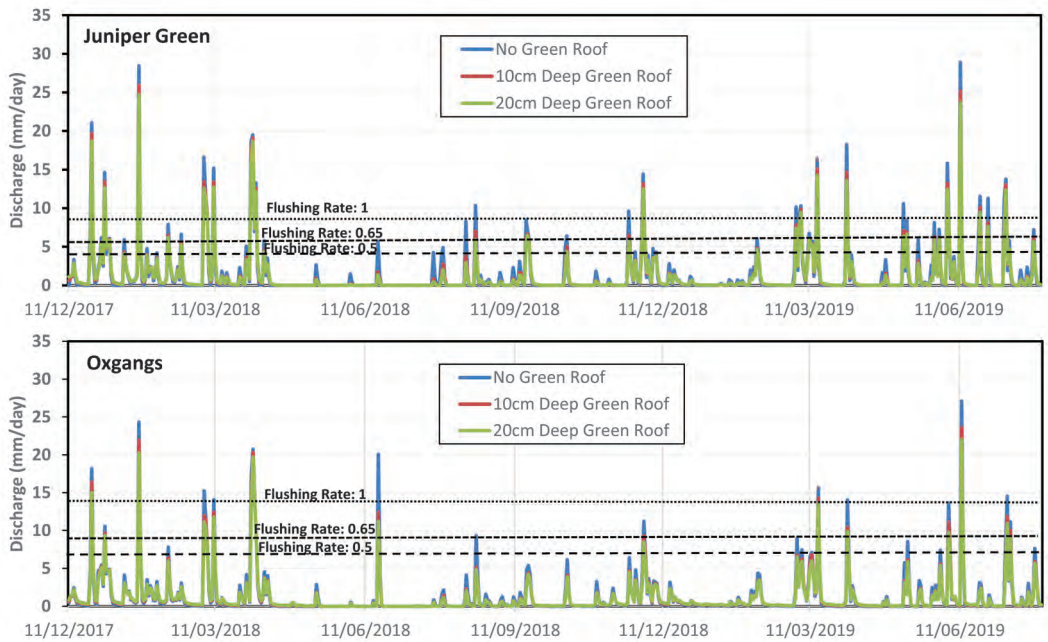

Figure 3: Simulated daily water discharges (mm/day) from the ponds. For both catchments, the effect of the green roofs is shown. Both simulated catchments use their nearest raingauge: Torduff at Juniper Green and Comiston at Oxgangs. The dashed lines indicate the equivalent levels of flush rate (per day) corresponding to the reproduction rate of slow (0.5/d) and faster (1/d) phytoplankton growth. Note that the medium value (0.65/d) corresponds to the typical value of cyanobacterial growth.

be more pronounced. It is also worth pointing out that the antecedent conditions strongly influence the magnitude of discharge resulting from specific precipitation events. In some cases, the green roofs would be saturated at the start of an event, whereas in other cases (e.g. 19.6.2018) the antecedent conditions would have made the soils drier so the roofs have a bigger effect. Another interesting point is that the patterns of reduction in discharge simulated by SHETRAN appear to be broadly similar, and this similarity was further confirmed by forcing both simulations using the same precipitation data for both catchments. The detailed analysis (not shown) confirms the similarity of these patterns (r^2 = 0.82) and reveals that these reductions are slightly higher in Juniper Green because of the greater proportion of its catchment occupied by buildings. Overall, the discharge in the 20-cm GRs scenario over 17 months simulation period is reduced by 10.6% and 13.4% at Oxgangs and Juniper Green, respectively. These values are far below some of the reductions in the runoff rates reported in the literature – see e.g. [20] and references therein. The achieved reductions in discharge are, therefore, likely to be greater than our estimates. Consequently, the estimates in the increase of pond water residence time and the decrease of flush rate (see below) should be viewed as conservative as well.

Table 1 gives estimated water residence time under the examined scenarios for both ponds. Following the retrofitting of GRs, higher increases in residence time would be expected for Juniper Green. However, the key pattern emerging from this analysis is that under the normal operating conditions changes in water residence time in both ponds are expected to be rather limited. Nevertheless, there are a number of instances when some remarkable decreases in the flushing rate happen during the key seasonal stages of phytoplankton development, including, e.g. those when the flush rate drops below the equivalent value for daily increase in the slow-growing phytoplankton (Fig. 3).

2.2 Simulation of extreme events

Figures 4a and b present the results of CityCAT simulations for 1:100 year events (i.e. 100 years return period) of four different durations at Juniper Green and Oxgangs respectively. The differences in discharges under the examined scenarios are rather substantial and in all cases the green roofs reduce the peak discharge. It should be noted, however, that CityCAT does not in this case account for the antecedent conditions, so the reduction in discharge simulated in the model is a best-case scenario with dry initial conditions.

Table 1: Pond nominal residence times (days) estimated using SHETRAN. For both locations the depth of the green roofs on the buildings is shown. Both simulated catchments use their nearest raingauge: Torduff at Juniper Green and Comiston at Oxgangs. In addition, Oxgangs has been simulated using the Torduff rainfall so that a direct comparison between Juniper Green and Oxgangs can be carried out.

Month	Juniper Green -Torduff rainfall			Oxgangs – Torduff rainfall			Oxgangs – Comiston rainfall		
	0cm	10cm	20cm	0cm	10cm	20cm	0cm	10cm	20cm
Jan18-Mar18	3.5	3.6	3.7	6.5	6.6	6.7	7.1	7.2	7.3
Apr18-Jun18	8.5	9.5	9.8	16.5	17.2	17.5	12.0	13.4	13.8
Jul18-Sept18	9.6	13.9	15.7	21.0	32.6	35.1	24.8	36.7	38.8
Oct18-Dec18	7.6	8.8	9.0	14.0	15.6	15.9	14.0	15.6	15.8
Jan19-Mar19	6.9	7.5	7.6	12.8	13.6	13.8	13.1	13.9	14.1
Apr19-Jun19	3.9	4.6	4.7	7.7	8.8	9.2	9.7	11.2	11.5

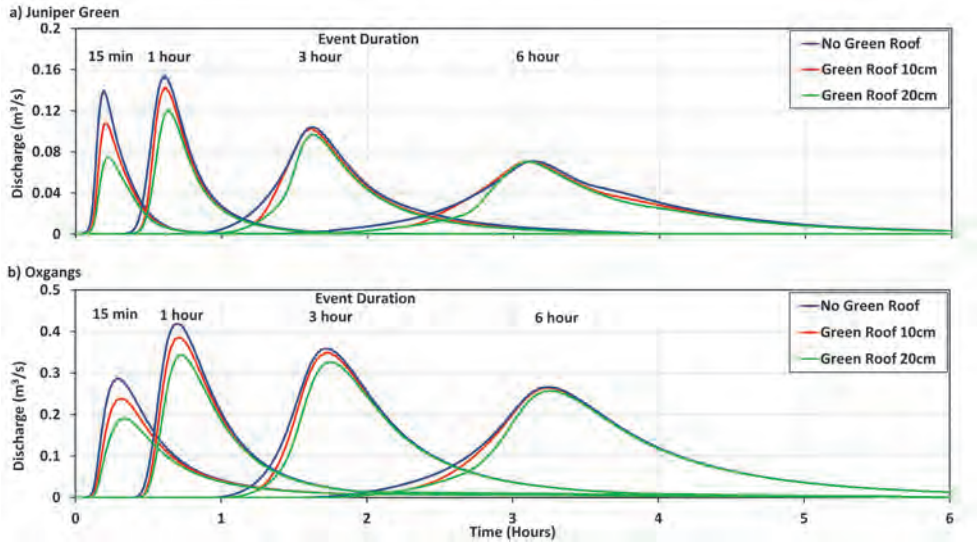

Figure 4: Simulated CityCAT discharges at (a) Juniper Green and (b) Oxgangs for 1:100 year events of four different durations with dry initial conditions.

The retrofitting of green roofs would have a greater effect for shorter duration events (e.g. 15 min – 1 h). For longer events (6 h), the effect of green roofs is bigger towards the start of the event and the effect on the peak discharge reduction is far less pronounced, as at this point during the event the green roofs become saturated and so unable to store any additional rainfall. It should also be noted that the introduction of green roofs would have a bigger effect on the peak discharge at Juniper Green for events of all durations. For the 15-min event, the reduction in peak discharge is 47.5% compared to a 33.6% reduction at Oxgangs. This reflects the higher roof coverage in its catchment.

3 WATER CHEMISTRY

Summary of the ICP analysis results for the monitored concentrations of selected chemicals are given in Fig. 5. As previously reported [13], Juniper Green water has lower electrical conductivity and lower total values of dissolved solids, which relates to its smaller and less diverse catchment in comparison with Oxgangs. This tallies well for comparison of concentrations of B, Ba, Ca, Mg, Na, Se, Sr, U and Eu, which are all significantly lower in Juniper Green water samples. Furthermore, the levels of K, Li, P, Rb, Sb, Se, Si and Lu in Oxgangs also rather substantially exceed those in Juniper Green, and although the differences for these elements were previously reported as not statistically significant (using multcompare.m Matlab script on the dataset comprising results for 9 urban ponds), the explicit comparison of the Oxgangs and Juniper Green data using the Kruskal–Wallis (KW) test revealed significant differences for these elements (Fig. 5). Somewhat lower values in Juniper Green were also noted for Tm. In fact, the values of B (data not shown) – the element known to affect macroinvertebrate community – were only detectable in Juniper Green pond water in July 2018, when they ranged between 11 and 15 ppb. In contrast, the majority of B analysis for Oxgangs were above the detection limit of 10 ppb, and some were as high as 50 ppb.

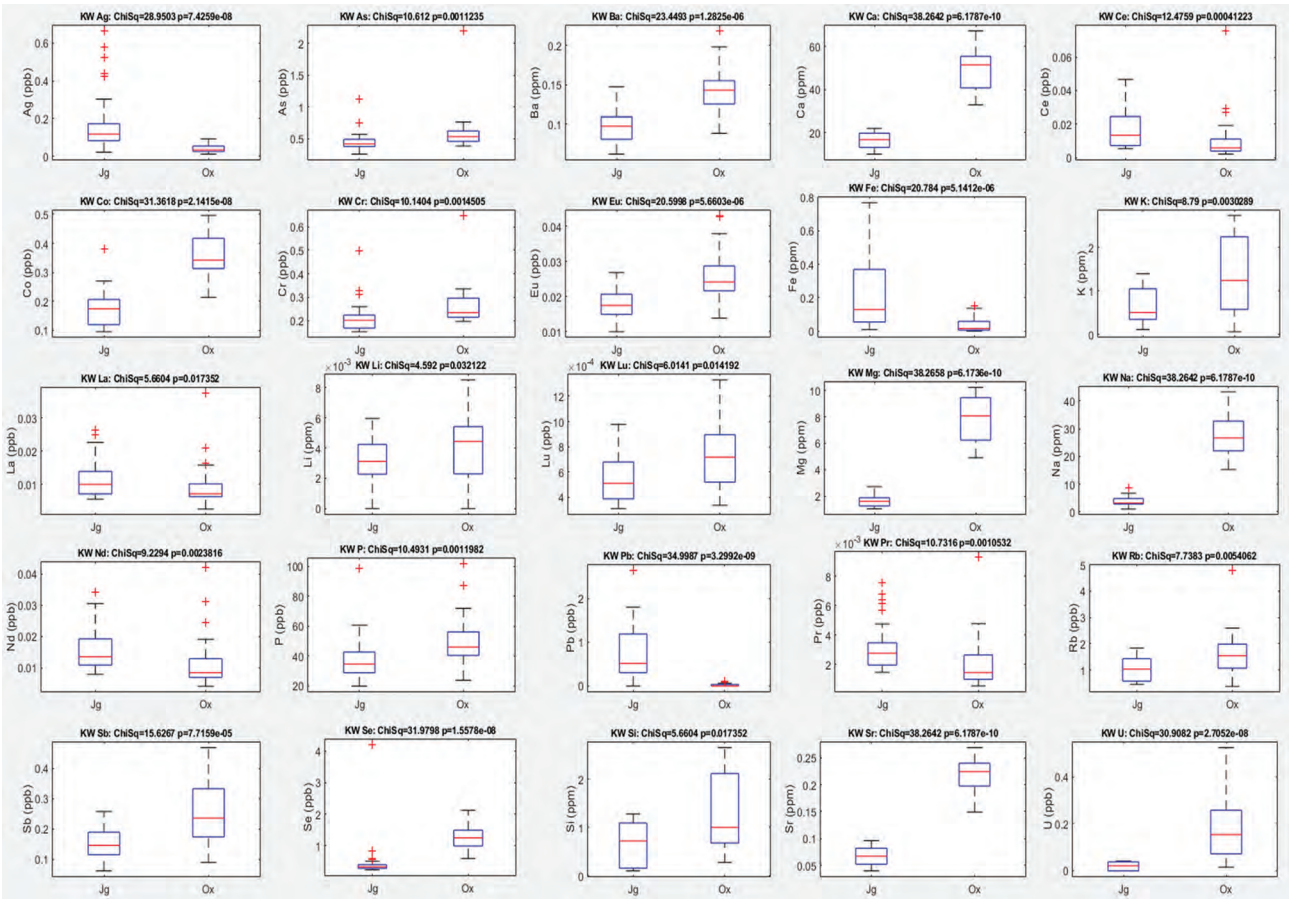

Figure 5: KW test comparisons of water concentrations for selected chemical elements. The values of Chi Square (ChiSq) statistics and its probability are listed in the panel titles.

It should be noted, however, that the concentrations of Pb and Ag were significantly lower at Oxgangs. Iron levels were also notably lower in Oxgangs, and although the previous analysis (using multcompare.m Matlab script on the dataset comprising results for 9 urban ponds) did not find a significant difference owing to the overlapping ranges, the explicit comparison of the Oxgangs and Juniper Green data using the KW test revealed significant differences (Fig. 5). Further significant differences were also obtained for La, Ce, Pr and Nd, which all appeared to be somewhat lower at Oxgangs. In addition, the values for Tb, Dy, Zn were somewhat lower in Oxgangs. It should also be noted that a previous study on suspended particles in Edinburgh ponds reported the presence of Au, Y and Ir at Juniper Green, and that was attributed using factor analysis to the effect of discarded electronics. It is therefore likely that the enrichment of Juniper Green water in Ag, Pb, Zn and some rare earth elements (REE) may, in part, have also resulted from discarded electronics. An observation of a very high outlier value for water concentrations of Ni (well over 200 ppb, data not shown) also tallies well with this explanation.

3.1 Potential Changes due to GRs

Whilst for many chemical elements there is no information on their potential levels in GRs' runoff, it is expected that, in general, the introduction of GRs would lead to substantial increases in both suspended and dissolved solids. Consequently, elemental levels in the receiving stormwater ponds would be expected to rise as well. The exact magnitude of these changes is uncertain and would depend on the specifications of the roofs' construction and the details of technology used. Of primary importance would be characteristics of the substrate. Currently, it is recommended that the substrate mix for GRs should include substantial amount of concrete [21]. Consequently, following the retrofitting of GRs we may expect substantial increases in runoff concentrations of Ca, Si, Al and Fe, which are the main elements comprising this material. There are also a number of admixtures variously used in concrete, including, e.g. sodium nitrate and calcium chloride. Such elements as, e.g. K, Ti, Mg and Mn may also be present in substantial amounts [22]. It should also be noted that GRs' substrates are specifically manufactured to promote plant growth, and may, therefore, be expected to have elevated concentrations of nutrients in their runoff.

A study in Canada reported that P, Al and Fe may be considerably increased in GRs runoff [20]. Increases in the concentrations of Mg, Ca, S, Cl and Na in GRs runoff (in comparison with conventional roofs) were also noted in that study, as well as increases in the detectability of such potentially problematic pollutants as Pb, Ni, Cd, Mo, V and Be (although it was noted that the levels were below statutory limits). However, the same study also found that many chemical variables had lower values in GRs runoff than in the runoff from conventional roofs. In particular, the runoff from conventional roofs had higher levels of Zn, Cu, Mn and polycyclic aromatic hydrocarbons (PAH). Furthermore, despite higher concentrations, the loads from GRs were lower for most chemicals due to lower runoff volumes.

Another study in Sweden [23] found that GRs appear to decrease the levels of Cd, and are very efficient in removing N from rain water; however, their runoff maybe enriched in Ni, Zn and especially in Cu, P, K, and DOC. Research in China [24] reported that runoff from GRs had lower pH than runoff from other roof types. The levels of electrical conductivity, total nitrogen, total organic carbon, COD, Cl, K, Na, Ca, Mg, Cu and Si were increased, whilst the concentrations of P and F were unaffected.

A potential of GRs to increase runoff pH was also highlighted by a study in Singapore [25]. That could be beneficial for neutralising the effects of acid deposition. However, the runoff pH does not appear to be a problem for our ponds. The same study considered a comprehensive number of chemicals and highlighted the elevated levels of phosphates and nitrates in GRs runoff. The runoff also included significant amounts of Na, K, Ca, Mg, Li, Fe, Al and sulphates, and the variability in the monitored chemicals was influenced by the characteristics of substrates and the details of precipitation patterns. However, such potentially important pollutants as Pb, Cd, Cr, Co and Mn did not appear in significant quantities [25].

In summary, although the exact changes are uncertain, there is a risk of water quality deterioration. Detailed considerations of interactions between chemistry and hydrology are indispensable for the correct assessment of the elemental budgets [26, 27] and further studies are needed. Furthermore, pollutants are readily adsorbed to suspended particulate matter (SPM). The dynamics of SPM in aquatic ecosystems is complex [28–31], and further research is required in that respect as well.

4 HYDROBIOLOGY

This section documents the differences and similarities between the current hydrobiological communities of Oxgangs and Juniper Green ponds. The potential changes to the community structure and patterns of ecological interactions are addressed in the discussion.

4.1 Plankton

There are a number of notable similarities and differences between planktonic community dynamics and composition at two ponds. In particular, it is worth pointing out the following features.

Firstly, the phytoplankton community at Oxgangs appears to be characterised by spring and autumn diatom blooms, with such genera as, e.g. *Synedra*, *Cocconeis* and *Epithemia* all frequently encountered [13]. The end of the spring maximum may be caused by a combination of factors related to grazing, hydraulics, and nutrient availability, and appears to be followed by a phytoplankton minimum in early Summer. Diatoms (including e.g. *Synedra* and *Epithemia*) are also encountered in Juniper Green, but less regularly and their planktonic forms have not been observed in blooming quantities. The clear water phase at Juniper Green was registered at the end of winter, and the responsible factors are likely to include low light and temperature, as well as high wash out rate due to the higher precipitation.

Secondly, the phytoplankton community at Juniper Green appears to be dominated by *Spirogyra* and (to a lesser extent) *Peridinium*. These taxa also occur in Oxgangs, but far less regularly and mostly in lesser quantities, although *Spirogyra* was prominent in July 2018 and May 2019 samples [13]. *Mougeotia*, on the other hand, at times becomes abundant at Oxgangs, whilst its occurrence in Juniper Green is much less prominent.

Thirdly, the cyanobacteria are encountered in both ponds, and usually in higher density in Summer and Autumn. Overall, however, they are more common in Oxgangs. Furthermore, in Juniper Green *Microcystis* is encountered much more often than *Oscillatoria*, whilst the opposite is true for Oxgangs where *Microcystis* is very rare.

Fourthly, although both ponds have *Cyclops*, *Daphnia* and *Chydorus*, such representatives of zooplankton community as *Diaptomus* were only encountered at Juniper Green. Furthermore, although a number of rotifer species were encountered at both ponds, the only regularly sampled species was *Keratella quadrata*, and only in Juniper Green.

4.2 Meiofauna

Currently, the macroinvertebrate community in both ponds is mainly comprised of animals which are able to tolerate a wide range of conditions, including, e.g. *Radix balthica* and *Asselus aquaticus*, as well as representatives of *Corixidae*, *Chironomidae*, *Coenagrionidae* and *Planorbidae*. In both ponds there are also representatives of animals characteristic of medium quality conditions, e.g. *Limnephilidae*. Macroinvertebrate indices ASPT and WHPT indicate that biological water quality is better at Juniper Green [13], and that tallies well both with the water chemistry data discussed above, and the fact that *Phryganeidae* (another indicator of medium quality conditions) are found in Juniper Green only.

It should also be noted that there are notable differences in the community structure. The insect predators in Oxgangs are rare, whilst the predatory *Chaoborus* larvae (absent from Oxgangs) and hemipterans *Notonecta glauca* (rare in Oxgangs) are common in Juniper Green. The scarcity of insect predators in Oxgangs has been attributed to the presence of *Gasterosteus aculeatus*. These fish are absent from Juniper Green, which is a prerequisite for the population of palmate newts *Lissotriton helveticus* thriving at that site despite a very limited terrestrial habitat, which is also important for these animals. It should be noted that a single palmate newt female was previously recorded in Oxgangs by the NatureScot research team (David O'Brien, personal communication). However, neither their extensive search nor our sampling produced any evidence of other adults, juveniles or eggs. Hence there is no evidence of successful breeding of the newts there, and the Oxgangs pond site maybe acting as a sink for their population.

5 BIODIVERSITY OF PLANTS AND FUNGI

As has previously been documented [13], both case study sites are characterised by substantial species richness. Owing to its bigger size, there are many more vascular plants recorded at Oxgangs than at Juniper Green (103 vs 22, see Tables 2 and 3). The numbers of bryophytes, however, are less different (22 vs 16), and Juniper Green was shown to host a rare species *Phaeoceros laevis* [13]. The majority of vascular plants at Oxgangs are herbaceous (60 species) whilst there are 16 species within the 'trees/shrubs' category. This pattern also holds at the Juniper Green site (15 species of herbaceous plants, and 6 species within the 'trees/shrubs' category). It is also of interest to note that the majority of vascular plants at Oxgangs are native, and only 17 species (8 trees/shrubs, 9 herbs) belong to the non-native category. At the Juniper Green site, however, this pattern is reversed for the 'trees and shrubs' category, with almost all (and potentially all) of them being planted introductions with which the area around the pond has been landscaped. The aquatic and mesic habitats at this site are dominated by native taxa though.

It should also be noted that in addition to the purely aquatic habitat specialists, both sites host many plant species characteristic of mesic and terrestrial habitats (there are only 9 and 6 purely aquatic specialists at the Oxgangs and Juniper Green sites, respectively). That is very relevant for understanding the full extent of contribution these sites make to the local habitat diversity and their functioning as wildlife corridors. Terrestrial biodiversity is often ignored in studies of urban ponds. However, the area immediately adjacent to the water body and the nearby green space provide a plethora of microhabitats suitable for species with a wide range of ecological preferences. This is evident not only for plants (Tables 2 and 3) but also for fungi, and the previous research has documented 4 and 11 taxa of epiphytic lichens, as well as 2 and 5 non-lichenised fungi at Juniper Green and Oxgangs respectively [13].

Table 2: Vascular plants recorded at Oxgangs pond (Source: Krivtsov et al, 2020 [13]). (T) indicates species occupies terrestrial habitat, (M) indicates species occupies mesic habitat, (A) indicates species occupies aquatic habitat, (E) indicates epiphyte. * indicates species/cultivar is not native to UK.

Trees and shrubs:		
Acer pseudoplatanus (T) *	*Ilex aquifolium* (T)	*Rubus idaeus* (T)
Berberis thunbergii (T) *	*Prunus avium* (T)	*Salix sp* (T)
Betula pendula (T)	*Pyracantha sp* (T) *	*Sorbus aucuparia* (T)
Buddleja davidii (T) *	*Rosa sp* (T)	*Symphoricarpos albus* (T) *
Escallonia sp (T) *	*Rosa rugosa* (T) *	*Weigela florida* (T) *
Hedera helix (T/E)	*Rubus fruticosus* agg (T)	
Herbaceous plants:		
Agrostis capillaris (T)	*Geranium robertianum* (T)	*Potamogeton natans* (A)
Anthriscus sylvestris (T)	*Geum urbanum* (T)	*Ranunculus flammula* (A)
Arrhenatherum elatius (T)	*Glyceria maxima* (M)	*Ranunculus lingua* (A)
Atriplex patula (T)	*Heracleum sphondylium* (T)	*Ranunculus repens* (T)
Aster sp (T) *	*Holcus lanatus* (T)	*Rorippa sp* (A)
Bellis perennis (T)	*Iris pseudacorus* (A)	*Rumex obtusifolius* (T)
Bromus sp (T)	*Jacobaea vulgaris* (T)	*Sagina apetala* (T)
Calendula officinalis (T) *	*Lapsana communis* (T)	*Sagina procumbens* (T)
Caltha palustris (M)	*Lagarosiphon major* (A) *	*Sedum sp* (T)
Capsella bursa-pastoris (T)	*Lemna minor* (A)	*Senecio vulgaris* (T)
Cardamine hirsuta (T)	*Lolium perenne* (T)	*Sinapis arvensis* (T)
Centaurea nigra (T)	*Lotus pedunculatus* (T)	(archaeophyte)
Cerastium fontanum (T)	*Lycopus europaeus* (M)	*Sisymbrium officinale* (T)
Ceratophyllum demersum (A) *	*Matricaria discoidea* (T) *	*Sonchus asper* (T)
Cirsium arvense (T)	*Mentha aquatica* (M)	*Sonchus oleraceus* (T)
Cirsium vulgare (T)	*Menyanthes trifoliata* (A)	*Stellaria graminea* (T)
Dactylis glomerata (T)	*Mimulus sp* (M) *	*Stellaria media* (T)
Digitalis purpurea (T)	*Myosotis arvensis* (T)	*Trifolium pratense* (T)
Dryopteris sp (T)	*Narcissus pseudonarcissus* cv. (T) *	*Trifolium repens* (T)
Epilobium hirsutum (T)	*Phalaris arundinacea* (M)	*Tripleurospermum maritimum* (T)
Epilobium sp (T)	*Plantago lanceolata* (T)	*Taraxacum* aggregate (T)
Equisetum arvense (T)	*Plantago major* (T)	*Tussilago farfara* (T)
Erysimum sp (T)	*Poa annua* (T)	*Typha latifolia* (T)
(archaeophyte)	*Polygonum aviculare* (T)	*Urtica dioica* (T)
Festuca rubra (T)	*Polypodium sp* (T/E)	*Vicia hirsuta* (T)
Foeniculum vulgare (T) *		*Vinca major* (T) *
Galium aparine (T)		

Table 3: Vascular plants recorded at Juniper Green pond (Source: Krivtsov et al, 2020; [13]). See the caption of Table 2 for explanation of notations.

Trees and shrubs:		
Cornus sp (T) *	*Cotoneaster salicifolia* (T) *	*Picea sp* (T) *
Cotoneaster horizontalis (T) *	*Cotoneaster sp* (T) *	*Rosa sp* (T)
Herbaceous plants:		
Alisma plantago-aquatica (M/A)	*Crassula sp* (A) likely *	*Juncus articulatus* (T/M)
Callitriche stagnalis (M)	*Equisetum arvense* (T)	*Juncus effusus* (T/M)
Caltha palustris (M)	*Festuca rubra* (T)	*Nymphaea alba* (A)
Carex pendula (T)	*Hedera helix* (T/E)	*Phragmites australis* (A)
Carex pseudocyperus (M)	*Iris pseudoacorus* (A)	*Ranunculus lingua* (A)

5.1 Calcicolous Lichens

It should be noted that the lichen community at the Oxgangs site benefits from the presence of a wall constructed using stones in rip-rap (this type of gabion basket is not available at Juniper Green). Specifically, the top of the stones in rip-rap contains a more or less acid-loving type of community including *Caloplaca holocarpa*, *Porpidia crustulata*, *Rhizocarpon reductum*, cf. *Amandinea punctata* and *Trapelia coarctata*. The stones on the side of the same rip-rap host a more nutrient-rich community including *Caloplaca citrina* s.l., *Lecania erysibe*, *Lecanora campestris*, *Myriolecis* (*Lecanora*) *dispersa* s.l., and *Myriolecis* (*Lecanora*) *semipallida*. The nutrient enrichment here possibly reflects the inputs of nutrients washed off from soil above it and (lower down) also from the urine of dogs and foxes.

Nutrient enrichment at Oxgangs is also evident on the brick paving, which at the time of fieldwork was partially covered in canine excrement. The lichen community here is comprised of *Aspicilia contorta*, *Lecidella stigmatea*, *Myriolecis* (*Lecanora*) *albescens*, *Myriolecis* (*Lecanora*) *semipallida*, *Phaeophyscia orbicularis* and *Porina chlorotica*. In contrast, the brick paving on the path above the Juniper Green pond appeared to host only *Collema tenax* and *Xanthoria parietina*.

The mortar between the bricks at Oxgangs hosts the species characteristic of base-rich communities, including *Verrucaria* species (medium grey thallus, black partially-erumpent fruits) and an unidentified green sorediate crust with margins of nearly-continuous areoles with brighter yellowish-green soredia (when damp). In comparison, the base-rich community at Juniper Green is much more diverse; in addition to mortar the site also features a couple of concrete sills, a type of habitat lacking at Oxgangs (where the base-rich community is associated only with mortar). *Verrucaria* species (the same species as found on mortar at Oxgangs – characterised by thick medium grey thallus with partially – erumpent fruits) is thriving here. There are, however, a number of additional species, such as *Caloplaca holocarpa*, *Myriolecis* (*Lecanora*) *albescens*, *Myriolecis* (*Lecanora*) *hagenii*, *Myriolecis* (*Lecanora*) *semipallida* and *Verrucaria nigrescens*.

The walls at Juniper Green host *Caloplaca citrina* s.l., *Myriolecis* (*Lecanora*) *albescens*, *Myriolecis* (*Lecanora*) *dispersa* s.l., *Myriolecis* (*Lecanora*) *semipallida*, *Verrucaria* species 1 (no thallus apparent, partially-erumpent black fruits) and *Verrucaria* species 2 (pale greyish white thallus with small fruits). This community is broadly indicative of base-rich conditions,

probably attributable to the composition of the bricks and mortar. Despite the very different setting, without the evidence of allochthonous nutrient enrichment from use by domestic and urban mammals, the substrates of the walls and mortar support a similar base-rich community to Oxgangs. Nutrient enrichment is almost entirely absent on the pebbles under the ornamental waterwheel (nutrient-poor community) where there are such species as *Porpidia crustulata*, *Porpidia tuberculosa*, *Rhizocarpon reductum*, *Trapelia coarctata* and *Trapelia placodioides*, with the nutrient-loving *Lecania erysibe* on pebbles adjacent to the wall.

All in all, 17 and 20 calcicolous lichen taxa have been recorded on artificial substrates at Oxgangs and Juniper Green sites, respectively, thus providing a considerable addition to the biodiversity of these sites. It should be also noted that this account of calcicolous taxa is not comprehensive, as during the survey in Jan 2021 significant parts of the stonework were covered in frost and snow. It is, however, apparent that the lichens of these SUDS ponds sites are heavily dominated by those typical of nutrient-enriched sites, including mortar, concrete and ground in terrestrial urban environments, and that the degree of this enrichment is higher at Oxgangs. However, both surveyed sites have some small areas of nutrient-poor rock surfaces, like the tops of stones in the rip-rap around Oxgangs or the undisturbed landscaping pebbles behind the fence at Juniper Green. In both of these areas, ruderal communities of relatively common taxa have developed, marked by the distinctive dark patches of *Rhizocarpon reductum* in particular, a good indicator for this community. The less-organized looking *Porpidia crustulata*, with black apothecia scattered unpredictably across the thallus, is also relatively common, with a paler, more even texture.

6 DISCUSSION AND CONCLUDING REMARKS

The basic details of hydrology, ecology and multiple benefits provided by Oxgangs and Juniper Green ponds have been published before [13]. This paper has provided further information and a comparative summary describing ecological functioning, biodiversity, water chemistry and provision of ecosystem services by these case study SuDS ponds. The manuscript also gives an analysis of potential changes expected following the hypothetical retrofitting of GRs in the ponds' catchments.

There is unequivocal evidence that both SuDS ponds provide valuable multiple benefits related to the enhancement of local biodiversity, water quality improvement and alleviation of flood risk, which is in line with studies on other urban ponds [32, 33]. There is also a strong evidence that the retrofitting of GRs would further enhance flood resilience. It should also be noted that, based on studies elsewhere, the retrofitting of GRs is expected to increase the biodiversity of the area rather considerably. The retrofitting of GRs is unlikely to lead to any substantial changes in the floristic community associated with the ponds' study sites, although there might be some increase in species preferring stagnant conditions (e.g. *Callitriche stagnalis*). The terrestrial habitats would not be affected. It should be noted, however, that there may be potentially negative effects on the runoff water quality and biological community composition at the receiving SuDS ponds.

The observations on water chemistry summarised above implicate the impact of polluted runoff on both ponds. The magnitude of this impact, however, appears to be substantially greater for Oxgangs. There is also observational evidence (further confirmed through informal reports by local residents) that both ponds are affected by illegal disposal of discarded household items. This is particularly evident for Juniper Green, where a number of chemical signatures appear to originate from discarded electronic equipment. Overall, however, this pond is relatively oligotrophic.

The retrofitting of GRs may increase the ponds' water residence time and the overall amount of dissolved substances, including nutrients and a range of pollutants. The exact changes in the pollutant loads are uncertain, but for many elements the pond water concentrations are likely to increase. The increase in hardness, however, is likely to be beneficial for reducing toxicity of metals. Nevertheless, the combined effect of these changes may disturb the current balance in the ponds' ecosystems and lead to the changes in their hydrobiological communities. The bottom-up effects are likely to propagate to the upper trophic levels and affect the current patterns of ecological relationships involving plankton and meiofauna. The level of these risks are higher for Juniper Green, as it is a very small pond with relatively low concentrations of dissolved chemicals.

It is also noteworthy that the retrofitting of GRs would result in more high flow events being reduced towards and even below the 0.65 equivalent value of flush rate (corresponding to the usual daily increase in cyanobacteria). However, greater residence time at Oxgangs combined with further increase in its trophic status would also bring about a concern for the potential increase in the occurrence of cyanobacteria capable of producing neuro- and hepato-toxins [34]. Interactions among ecosystem components are complex [35–42]. Consideration of indirect effects is paramount for the correct understanding of the functioning of ecological and environmental systems [15], and our analysis highlights that. The present study is, therefore, relevant to the development of comparative theoretical ecosystem analysis (CTEA), and further research and any potential management actions would benefit from the application of the CTEA methodological framework specifically designed to study indirect effects [14].

It is worth emphasising that the research presented here highlights the positive synergistic effects resulting from a combined application of two types of BGI installations (SuDS ponds and GRs). In addition, our study also objectively considers potential trade-offs related to the water quality and ecological community composition. This is relevant to the framework of NBS, and in particular such GIS-based assessment tools as NCPT and NGPT [43–45], aiming to account for the combined changes in ecosystem services and the resulting gain in natural capital. Thus although the prospective of complete retrofitting of GRs in the case study catchments considered here may seem unrealistic due to the logistical and financial reasons (especially given that typically the roofs are of the pitched kind), this research, nevertheless, will be of use for practitioners planning new developments where the application of GRs and SuDS ponds is considered either simultaneously or as alternatives (such as, e.g. Meadowbank development in Edinburgh [46]). More generally, the CTEA methodology and the analysis presented here will be of value for any considerations of complex NBS alternatives, and is therefore relevant to the ongoing development of the BGC/Sponge Cities conceptual framework [2, 3, 47–51].

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INFLUENCERS OF HEALTH CARE WASTE GENERATION AT ENHLAZENI DISTRICT MUNICIPALITY, SOUTH AFRICA

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ABSTRACT
Healthcare waste (HCW) generation is influenced by myriad of factors. This paper presents empirical results on the factors that influence health care waste generation at Ehlanzeni District Municipality. In assessing these factors, the paper begins by examining the concept of HCW, their implication and classification criteria. Empirical data from 57 healthcare facilities were collected and analysed through descriptive and inferential statistics. The findings of this study confirmed, among others that the number of patients served per day (inpatients and outpatients), the number of personnel (staff), have an influence on the amount of HCW generated per day per kg, at different correlational levels. The number of patients served per day have proved a strong correlation with the amount of HCW generated per day per kg, as compared to the number of personnel. Among other findings, the study revealed that there are numerous factors that influence HCW generation at varying the degrees.
Keywords: healthcare waste, healthcare waste definitions, healthcare waste management, general healthcare waste, hazardous healthcare waste.

1 INTRODUCTION

The generation of healthcare waste (HCW) cannot be completely avoided because according to Choudhary and Slathia (2014), healthcare is an essential aspect of life. Instead, HCW should be efficiently managed. Firstly, this paper examines the concept of HCW. According to Bendjoudi, Taleb, Abdelmalek and Addou (2009), 'there are currently several terms used to describe waste that is generated from healthcare facilities' as confirmed by World Health Organisation (WHO, 1999;2004). Muhwezi et al (2014) confirm the previous findings by World Health Organisation (WHO, 1999;2004) and Bendjoudi et al (2009), that there has been some level of inconsistences about what is defined or characterise as HCW, globally. This paper attempts to firstly interrogate the common concepts that are interchangeably use for HWC. Not only is HCW inconsistently defined, but global studies show that there are different concepts used for HCW in different regions of the world namely, (1) biomedical waste, (2) medical waste, (3) hospital waste and (4) clinical waste. In Fig. 1, the frequency global studies that use either of the concepts interchangeably to HCW is presented.

According to Fig. 1, there are five key concepts fluently used for HCW stream. The frequency of choice of concepts appears to vary continentally. The second argument presented in this study is the sub-classification of HCW based on different groupings or categories. According to Minoglou and Komilis (2018), the most basic criteria for the classification of HCW is to differentiate between hazardous (infectious) and non-hazardous (non-infectious) categories. The non-hazardous fractions are also called general waste or non-infectious waste. According to Mohseni-Bandpei et al (2019), primarily, HCW classification criterion is characterised by the potentially infectious nature and toxicity of the waste materials or their components (Table 1).

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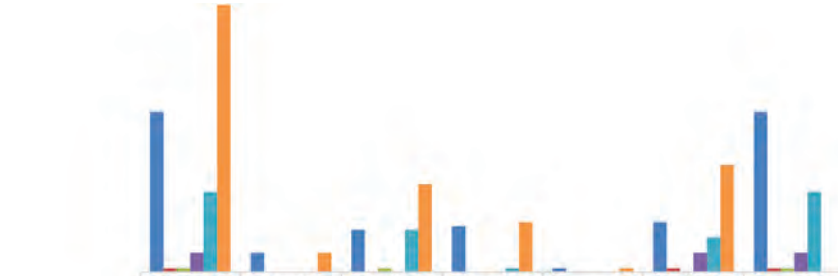

	Reviewed articles	Hospital waste	Medical waste	Biomedical waste	Clincal waste	Healthcare waste	Total
Asia	42	5	11	12	1	13	42
South America	1	0	0	0	0	1	1
North America	1	0	1	0	0	0	1
Europe	5	0	0	0	0	5	5
Africa	21	0	11	1	0	9	21
TOTAL	70	5	23	13	1	28	

Figure 1: Frequently used concept of HCW in five continents

Table 1: Ratio of general and infectious waste within HCW.

Author	Study area	General (%)	Hazardous (%)
Mazloomi et al (2019)	Iran	37	63
Aung, Luan & Xu (2019)	Switzerland	82.50	17.50
Aung, Luan & Xu (2019)	Myanmar: Yangon	29	71
Aung, Luan & Xu (2019)	Myanmar: Mandalay	17	83
Aung, Luan & Xu (2019)	Myanmar: Naypyidaw	30	70
Bhalla, Bandyopadhyay & Sahai (2018)	India	82.50	17.50
Minoglou & Komilis (2018)	Greece	80	20
Hameed, Riaz, Minallah & Munawar (2017)	Pakistan – Public	85	15
Hameed, Riaz, Minallah & Munawar (2017)	Pakistan – Private	86	14
Hameed, Riaz, Minallah & Munawar (2017)	Pakistan – Semi Government	84	16
Hameed, Riaz, Minallah & Munawar (2017)	Pakistan- Trust	86	14
Nemathaga, Maringa & Chimuka (2008)	South Africa	61	39
Mbarki, Kabbachi, Ezaidi & Benssaou (2013)	Morocco	70	30

The data in Table 1 show a range of 14% to 83% of the HCW being infectious, while 17% to 86% is general. On average, 36% of the waste materials are infectious as compared to 64% of general components, at 26% standard deviation. Half (median) of the data facilities generated 20% infectious and 80% non-infectious waste. Most of the data sources reported 18% and 83%, infectious and non-infectious waste fractions, respectively.

Secondly the classification of HCW is broadly categorised as infectious and non-infectious. These categories are further sub-classified according to their material composition. For example, according to Mishra et al. (2016) and Mazloomi et al. (2018), infectious waste is sub-categorised into pathological, pharmaceutical and chemical properties. It is noted from this discussion that as discussed earlier, some regions of the world have adopted their HCW concepts from the different HCW characterization classes, while others use the broad category than a sub-category (Acharya et al., 2014). Furthermore, USEPA (2011), Windfield and Brooks (2015), Mazloomi et al (2018) support a view that each HCW category at different classification levels may take either solid, liquid, gaseous state or a combination thereof.

Thirdly and most importantly, this study examined the factors that influence the generation of the HCW stream. Komilis, Fouki and Papadopoulos (2012), concluded that different categories of healthcare facilities drive HCW generation. Patwary, O'Hare, Street, Elahi, Hossain and Sarker (2009), identified the size and location of the healthcare facility as the second factor that influence the generation of HCW . In their study, Ptawary et al (2009) concluded that 'the amount of waste, and the proportion of hazardous waste varied significantly with the size and type of healthcare centres. Tabasi and Marthandan (2013) and Eker and Bilgili (2011) agree that the number of patients influence HCW generation. Thus, Eker and Bilgili (2011), argue that 'the generated waste quantities can be affected by the inpatient numbers and so the waste quantities from healthcare services can be evaluated using the number of patients visiting the healthcare facility per day. Hence, Eker and Bilgili (2011), suggest that an evaluation of the HCW generation rates can be done by determining the number of the visitors or both out and inpatients that visit a healthcare facility.

Tabasi and Marthandan (2013), identified (1) number of beds, (2) bed occupancy rates and (3) the type of hospitals or healthcare facility, as key drivers of HCW generation rate. There is some level of consensus about several factors that influence HCW generation ,that is evident from Cheng, Sung, Yang and Chung (2009) who concur that (1) the number of beds; (2) number of speciality beds, (3) bed occupancy, (4) number of infectious disease beds, (5) number of outpatients per day, (6) amount of waste recycled and (7) the proportion of patients treated per day influence HCW. Consequently, this paper reports on the influence of a selected number of common factors among the above discussed. A study from Irbid City by Bdour et al (2007), proved that public hospitals with equal numbers of beds, patients serve per day and staff numbers produced 6.1 kg of HCW per bed per day as compared to 4.02 kg in a private hospital of similar status and capacity. In another study in Taiwan, Cheng et al (2009) confirmed the influence of number of beds, bed occupancy rate and related factors on HCW generation rate. Shakiba and Mohagheghian (2018), Alwabr et al (2016), Hayleeyesus and Cherinete (2016), Aseweh (2013), Ali et al (2016), Khajuria et al (2007) and Pandey et al (2016) concur with the above factors as drivers of HCW generation rates. In this variability (Table 2), the efficiency of healthcare facility's production systems (including that of individual personnel) and the levels of developments in the study area emerge as other factors that influence HCW generation rates.

Table 2: Healthcare waste generation rate per kilogram per patient per day.

Author	Study area	Generation rate per kg per patient per day
Tesfahun et al., 2016	Ethiopia	0.245
Rabeie et al., 2012	Iran	3.1
Eker et al., 2011	Turkey	3.83
Eleyan et al., 2013	Palestine	0.4
Maamari et al., 2015	Lebanon	2.45
Gusca et al., 2015	Kazakhstan	0.814
Patwary et al., 2009	Bangladesh	0.499
Yong et al., 2009	China	0.65
Patil & Shekdar., 2001	India	1.5
Jang et al., 2006	Korea	1.3
Phengxay et al., 2005	Japan	0.62
Adsavakulchai et al., 2002	Thailand	0.4
Yelebe et al., 2015	Nigeria	0.18
Hassan et al., 2018	Sudan	0.6
Askarian et al., 2010	Iran	5.92
Hameed et al., 2017	Pakistan	1.28
Bdour et al 2005	Irbid City	6.1
Bdour et al 2006	Irbid City	5.62
Bdour et al 2007	Irbid City	4.02
Abah	Nigeria	0.62
Abah	Nigeria	0.63
Mbarki et al 2013	Morocco	0.53
Mean (Average)		*1.87*
Minimum		*0.18*
Maximum		*6.1*
Mode		*0.4*
Median		*0.73*
Standard deviation		*1.97*

From Table 2, it can be deduced that on average, a patient generates 1.87 kg of HCW per day. The generation rate ranges from 0.18 to 6.1 kg per patient per day, at 1.97 kg standard deviation. Most studies found a 0.4 kg generation rate per patient per day, while half of the reviewed studies per patient HCW generation rate was 0.73 kg.

2 MATERIALS AND METHODS

A survey was used carried out in selected 57 private and public health care facilities in Enhlazeni district. All questions were based on the variables of interest of the study and their related sub-variables (Mouton, 2013). Descriptive statistics were used to organise, summarise and present data, as recommended by Keller (2014). The data and information were thus presented using graphs and numerical techniques such as the calculation of central and variability measures (Creswell, 2009). Furthermore, inferential statistics were used to draw conclusions and inference about the relationship between the number of patients served per day and personnel correlated with the amount of HCW generated per day per kg. further analysis of the efficiency profiles of the 57 healthcare facilities (which were randomly selected from a list of existing facilities) were also done through observation of the peak points of a three-lined graph. Empirical results were analysed and compared with the findings of the literature-based analyses. Microsoft Excel 2013 was used for all statistical calculations. Lastly, to analyse some qualitative data, an explanatory analysis was used (Gibbs, 2007; Creswell, 2009).

3 DISCUSSION OF RESULTS

Empirical data was collected from 57 healthcare facilities which are private and public, constituting different categories, different operations and sizes that generate waste stream that falls within the definition of HCW (Fig. 2).

The empirical results in Fig. 2 identify hospitals, clinics, pharmacies, healthcare centres, medical practices and specialised medical centres or facilities as primary HCW generators within Ehlanzeni District Municipality. These facilities vary in sampled numbers and are further classified into private and public. In Fig. 3, the association between the number of healthcare staff (all-inclusive) and the HCW generation rate per day are tested. Table 3 presents the key central and dispersion measures of the number of staff, patients per day, operational days of a healthcare facility per week, the amount of HCW generated per week per kg (general, infectious and combined).

Comparatively analysis (where possible) of HCW generation quantities and rates in Tables 1, 2 and 3 show the variability of generations across many variables and parameters. Figure 3 presents the influence of staff numbers on HCW generation per kg per week.

Empirical data confirms that the number of patients that the healthcare facilities at Ehlanzeni District Municipality serve per day correlates strongly and positively with the

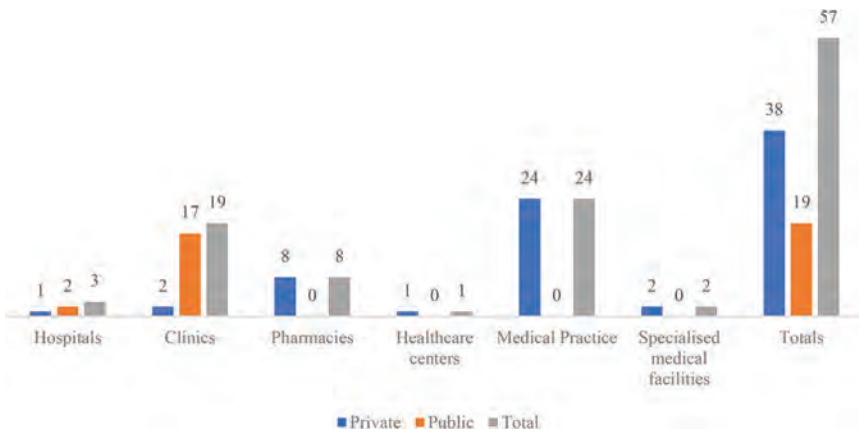

Figure 2: Different categories of healthcare facilities at Ehlanzeni District Municipality.

Table 3: Descriptive statistical analysis of the number of staff, patients per day, operational days of a healthcare facility per week, the amount of HCW generated per week per kg.

Variables	Mean	Min	Max	Median	Mode	Standard deviation
Total number of staff per healthcare facility	54.1	1	1,188	7	3	192.91
Number of patients served per day	135	0	1,000	40	10	0.79
Number of operational days per week	6.14	5	7	6	7	200.76
Infectious waste generated per week per kg	81.7	0	2,403	7.45	0	347.21
General waste generated per week per kg	23.7	0	1,000	1	0	133.56
Total waste generated per week per kg	102.82	0	3,403	11	3	471.75

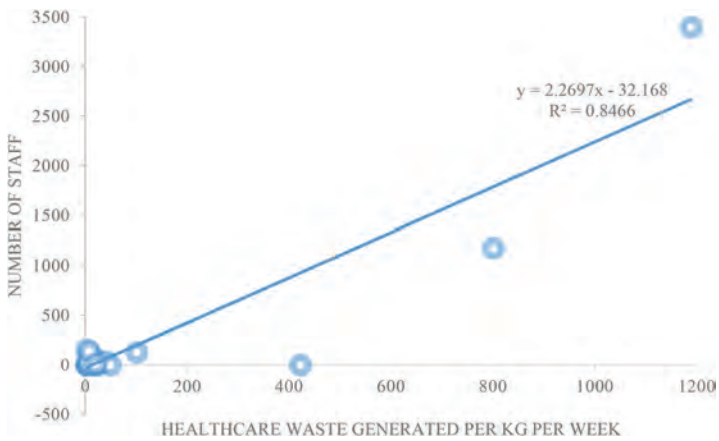

Figure 3: Influence of patient numbers per day on HCW generation per kg per week.

amount of HCW generated per day at a R^2= 0,84, which is equal to P= 0,84. In contrast, Fig. 4 presents the contrast with regards to the influence of staff numbers on the amount of HCW generation per day per kilogram.

The correlation between the number of staff and the amount of HCW generated per day per kg proved existent and weak, but positive at R^2=0,81. Lastly, Fig. 5 displays a comparative analysis among three variables (patients per day, number of staff & the amount of waste generated per day).

It is evident in Fig. 5, that the increase in staff numbers and patients served per day does not always correspond with the amounts of waste generated per day, as evident from the peak points of each variable. Observing each variable in comparison to the other two per healthcare

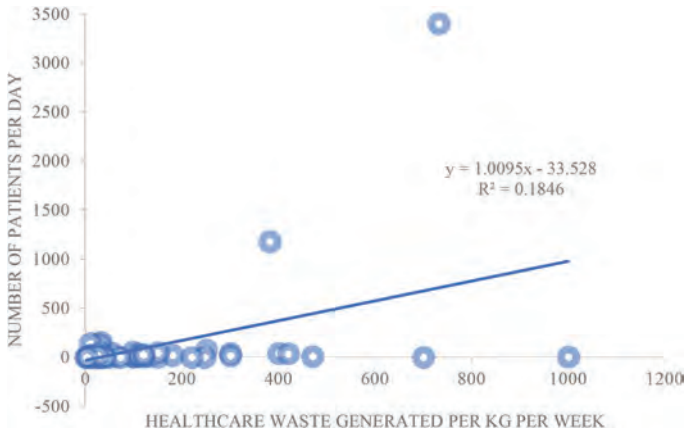

Figure 4: Influence of the total number of staff members on the amount of HCW generated per day per kg per healthcare facility.

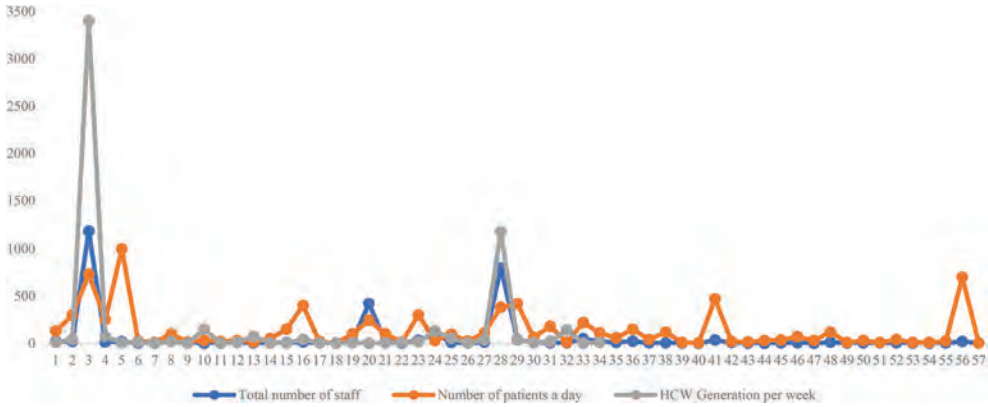

Figure 5: Relationship among number of patients and staff per day and amount of waste generated.

facility, in few instances (at facility 3,10,13,24, 28 and 32) the amount of waste generated per day per kg exceeded the number of patients per day and staff. This observation highlights an increase in waste quantity generated per patient and staff member per kg per day.

The number of patients in facilities (1, 2, 5, 8, 15, 16, 19, 21, 23, 25, 27, 29, 30, 31, 33, 34, 35, 36, 37, 38, 41, 46, 48, 50, 52 and 56) is higher than both the number of staff and the amount of HCW generated per day per kg. from this observation, the identified healthcare facilities are more efficient in their ratio of HCW generation per served patients per day. This is the most desirable state of production, provided that the quality of service given to each patient remains at its best, as defined by Machete et al (2015). In contrast, healthcare facility number 20 has a high number of staff than the number of patients served per day and the amount of HCW generated per day per kg. from this study, facility 20 appears as the most inefficient healthcare facility of all.

4 CONCLUSIONS

This paper investigated the influence of patient served per day and staff number on health care waste generation at Ehlanzeni District Municipality. Available literature revealed that HCW generation is influenced by myriad of factors, including the number of personnel and patients served per day. Empirical data from the 57 healthcare facilities in Ehlanzeni District Municipality confirmed the influence of number of patients served per day and personnel at varying regression levels. The number of patients served per day have proved a strong correlation with the amount of HCW generated per day per kg, as compared to the number of personnel. This paper also analysed efficiency levels of healthcare facilities with reference to the ratio of HCW generation against personnel numbers and that of patients served per day. The findings revealed several efficient healthcare facilities, with one extremely inefficient facility.

The findings of this study are important in setting the fundamental base for efficient assessment of HCW generation and identification of factors that drive HCW generation. The knowledge of these factors and their prioritization serve as causation and priority factors that need to be prioritised, if a healthcare facility intends to reduce its waste generation quantities and rates. It also serves as a guideline for prioritization of cost allocation in the prevention of HCW generation budgeting. The comparative analyses of HCW generation rates across various variables between available literature and empirical studies, provide a platform for future scholars to understand the significance of the use of available literature as a baseline for performance assessment, against which performance should be measured.

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IDENTITY, HEALTH AND URBAN LIVEABILITY: CREATING SPACES FOR PEOPLE

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ABSTRACT

The study illustrated in the paper was carried out in the framework of the ISMed-CNR research titled *Analysis and design of the contemporary territory: identity, health and urban liveability for resilient and sustainable places*, the INU Community *Public Space*, both coordinated by the author, and *Urban Maestro. New Governance Strategies for Urban Design* Horizon 2020 research project.

The ISMed-CNR research aims at identifying methodologies, databases and guidelines to support policy makers, professionals and scholars in the realization of healthy and liveable public spaces.

The Community Public Space has the objective to collect best practices of public space in Italy, starting from the Charter of Public Space adopted during the second Biennial of Public Space held in Rome in 2013.

The Urban Maestro Project – coordinated by the UCL and in partnership with UN-Habitat – 'looks at the ways European cities are being designed and financed, focusing on innovative ways of generating and implementing urban spatial quality'. Among the objectives, the project has the comparison of the experiences in Europe to international practices. Accordingly, the author, as a member of the Advisory and Support Group, shared the Italian good practices in the public space field.

Starting from these premises, the main results of this study will be illustrated. The Charter of Public Space is a sort of guidelines for liveable and sustainable public spaces. In order to comprehend the relationships between theory and practice and verify the validity of the Charter after 10 years of its creation, about 30 Italian case studies were collected. Of these, emblematic case studies with particular attention to the sustainability meant in its three-fold meaning will complete the paper.

Keywords: best practices, public spaces, sustainability, urban liveability, urban design, urban regeneration.

1 INTRODUCTION

The typologies of the public spaces are increasing changing, welcoming new uses, materials and urban furniture, trying to meet more needs together, including walking, cycling, sport, games for all ages and abilities, specific design for the protection by flood and other environmental events and the presence of wireless and qrcodes to have information of many kinds [1-11].

The new or regenerated sites not always are sustainable and of quality. For this reason, a Charter of Public Space was carried out and adopted in the framework of the second Biennial of Public Space held in Rome in 2013 [12]. The Charter is composed by 50 principles that are a sort of guidelines for both quality and sustainable public spaces.

Its main criteria are based on that the Charter – as reported in it – should contain reasonable and shared principles with regard to the conception, the design, the realization, the management, the transformability and the enjoyment of public space and, just like public space, accessible to all. The Charter of Public Space aims at serving all those who believe in the city and in its virtue in encouraging social interaction, encounter, togetherness and freedom, and in it calling for giving life to these values through public space. At the same time, cities show the worsening of economic, social, ethnic, cultural and generational inequalities. For

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this reason, public space should be the place where citizenship rights are guaranteed, and differences are respected and appreciated.

Starting from these premises, the present study, aimed at comprehending the relationship between theory and practice and verify the validity of the Charter after 10 years of its creation, was carried out by the author in the framework of the ISMed-CNR research titled Analysis and design of the contemporary territory: identity, health and urban liveability for resilient and sustainable places, the INU Community Public Space, both coordinated by the author, and Urban Maestro. New Governance Strategies for Urban Design Horizon 2020 research project.

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The ISMed-CNR research aims at identifying methodologies, databases and guidelines to support policy makers, professionals and scholars in the realization of healthy and liveable public spaces and the creation of indices capable of providing a numerical evaluation of the degree of health and liveability of a place.

The Community Public Space of the INU – Italian Institute of Urban Planning – has the objective to collect best practices of public space in Italy, starting from the Charter of Public Space.

To achieve the aim of the whole research, about 30 case emblematic studies were collected. The criteria to choose the categories of the case studies were multiple, namely: parks, transportation open-air hubs, waterfronts, squares, gardens, nature paths and projects on large scale [13].

Accordingly, the paper is organized as follows. The second section will show the database used for the collection of information concerning the case study and the recent update with respect to the current Covid 19 emergency. Section 3 will report the case studies which are particular emblematic for to their social, environmental and economic sustainability, achieved in different ways. Finally, section 4 shows the main changes at the principles of the Charter and draws the conclusion.

2 THE DATABASE

The database was created collecting information useful both in the phases of design and realization of a public space, and in the management ones. The data are collected by different sources, including information by the professionals or technicians who realized the spaces, internet, bibliographical references and on-site visits.

The first elements are the year of realization, the city, the address, the surface, the planimetry and the images. These elements are important to localize the public space and understand the dimension, the kind of project and its design.

Then the other important elements are constituted by: the Institutions that are involved – public and/or public; the funds – public and/or private – for the realization and, if previewed, the management; and the urban project or planning tools of reference.

The kind of uses and fruition are the other factors that contribute to the comprehension of the quality of the space together with the elements that testify the success.

Finally, the presence on the social media and relative, pages, hashtag and followers, the bibliography and sitography.

All these elements are related to both tangible and intangible data and contribute to the whole knowledge and success of the public space in object.

Thanks to the flexibility of the database, this was slightly adapted to allow the collections of elements to comprehend changes of the spaces in Covid 19 phase. Indeed, due to the current pandemic event, public spaces were not used for months and then reopened, requiring suitable physical distance between people to avoid crowdy situations; accordingly, some information were added to the database aimed at verifying their changes in the current Covid period [19].

The update of the database and of the case studies allowed to update the Charter of Public Space as well.

3 THE CASE STUDIES

The case studies of the whole research concern squares, gardens, parks, transportation open-air hubs, waterfronts, nature paths and projects on larger scale.

The public spaces which will be illustrated in the following concern: ArteNatura Park in Trento, Trentino Alto Adige Region; the Public Garden, in San Donà di Piave, Veneto Region; Portello Park, in Milan, Lombardia Region; the Gardentopia Gardens in Matera, Basilicata Region; the Open Laboratory Project in Bologna, Emilia Romagna Region; and Piazza Matteotti in Catanzaro, Calabria Region [13].

These emblematic case studies are related to one or more principles of the Charter. The general framework which emerges shows different design, planning, cultural, geographical, social and financial factors that can determine in multiple ways the quality and sustainability of a public space [14-19].

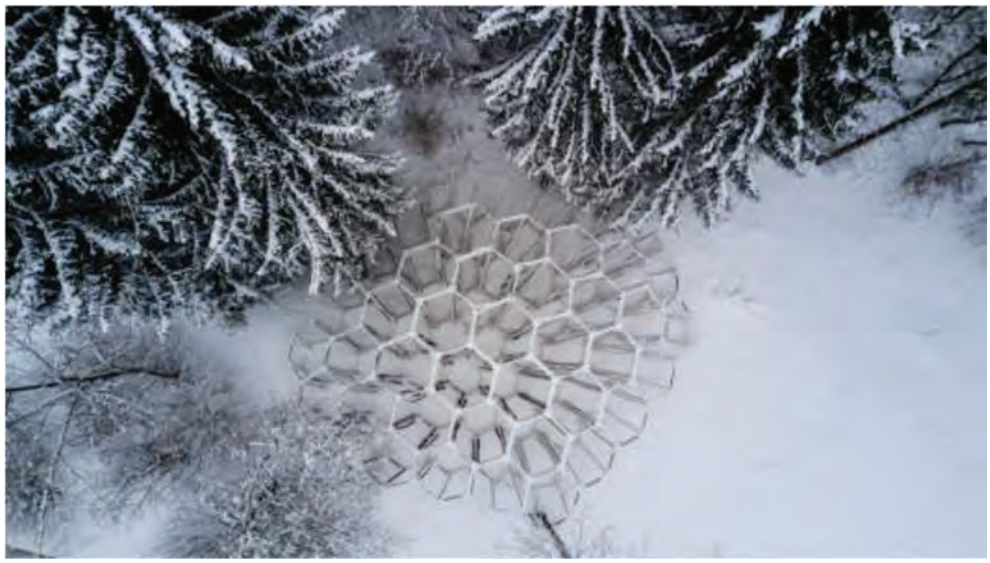

Figure 1: ArteNatura Path, Daniele Salvalai – L_alveare (Source: Photo by Giacomo Bianchi, Copyright Arte Sella).

The first case is the ArteNatura Path in Val di Sella (Trentino Alto Adige, North of Italy) which has existed since 1986 with the first installations and exhibitions created in the garden of Villa Strobele in Val di Sella. Since 1996, the Arte Sella project has developed along a wood path on the southern side of Armentera Mount: this is how the ArteNatura path is defined, an itinerary that *winds through the woods*. Since 1998, the area of Malga Costa has been added to the ArteNatura itinerary, an exhibition venue and then a concert hall.Val di Sella is accessible from Borgo Valsugana. The surface of ArteNatura route is 3 km, of which Malga Costa area is 1 km and that of Villa Strobele is 500 m. The Malga Costa area is owned by the Municipality of Borgo Valsugana, while the garden of Villa Strobele is privately owned, leased to Arte Sella.

The Institution involved in the creation of the space is ArteSella Association. The Institutions involved in the space management are as follows. Contribution: Autonomous Province of Trento – Trentino Alto Adige Region – Municipality of Borgo Valsugana – APT Valsugana – Service for employment support and environmental enhancement – CARITRO Foundation – Valsugana and Tesino Community. Sponsor: Montura – Ceramiche Keope – Dolomiti Energia – Levico – Finstral – Nerobutto – Foradori – Ferrari – Cassa Rurale Valsugana and Tesino – Consorzio Lavoro Ambiente – Ecoopera – Ottica Valsugana – Grucolo Refuge. Partner: European land + art network – Grandi Giardini Italiani – Trentino – The sounds of the Dolomites – Opera Estate – La Coccinella – Lito Delta – Silvana Editoriale – Sadesign – S.T.E.P. – T.S.M. – Science Museum – MART – Buonconsiglio Castle – FAI – Coop API – Borgo Valsugana Library – Forestry and Fauna Service of the Autonomous Province of Trento – De Bellat Foundation – Dancing Museums – Italian Touring Club. Media Partner: crushsite.it

The funding for space management are public (18%) and private (sponsors and tickets). As regards the urban planning tools of reference, in the third variant of the PRG – Regional General Plan – (November 2018) the park falls within the wooded area.

As regards the policies activated and types of use, this is a path in the mountains between art and nature, for walking, stopping and observing. In the last 30 years, dance, music and art in all its forms have assiduously organized in the paths of Arte Sella, giving shape to unique projects and events, such as Fucina Arte Sella or La Natura del Pensiero.

These are mountain paths with small and somewhat steep sections. Therefore, it is not possible to access with wheelchairs. The 'ArteNatura Path' is freely accessible, the path at Malga Costa is subject to a fee.

The Arte Sella Association constantly collaborates with Italian and foreign artists and cultural associations. The new projects ensure that the park has become not only an artistic but also a social and cultural centre of prominence and reference.

The local community is very close to the cause of the park, as on the occasion of the fundraising for the damage of bad weather in a few hours a lot of money was raised, and part of the population decided to materially help the foundation. In the current Covid 19 period specific paths have been carried out to allow a safe and agreeable visit.

With respect to the social network, on there is the hashtag: #artesella; on Facebook: Arte Sella page has 26,284 followers and 26,202 likes; on YouTube it is present but not with its own channel. Within these social media, there are no photo of people with face mask

The second case is the Public Garden, in San Donà di Piave (Veneto Region, North of Italy), which was realized between 2004 and 2007. The surface is of 20,000 sqm and the property is public (Fig. 2).

The Institutions involved in the creation of the space include the Municipality of San Donà di Piave and Borgo Vecchio Consortium, while the institution involved in the space

Figure 2: San Donà di Piave, Public Garden (Source: CZstudio).

management is the Municipality of San Donà di Piave. The urban project was carried out by Cino Zucchi Architetti.

As regards the type of uses, the park is a typical meeting place designed for both young and old people. It is used as a place for reading, resting and feeling tranquillity. To isolate the area from the parking lot and the surrounding suburbs, dunes and embankments were built. The park is also equipped with pedestrian paths, seats, auditorium, fountain, children's meeting place, cycle paths and picnic areas, made with white stones covered by white concrete. A concave space, defined by trees, lights and seats – always in white stone – welcomes an informal amphitheatre to host events. Furthermore, there are a series of radial paths that connect the central nucleus of the park with the pedestrian and cycle paths that connect the district to the city. The children's playground is protected by a wooden spiral and characterized by a high lamp that comes out of the ground.

The park is fully accessible on foot or with wheelchairs. It is also easily accessible by emergency vehicles in case of need.

Among the elements that testify the success of the case study, spaces of different environmental qualities have been created (children's play areas, small sports fields, etc) which are easily recognizable by all and safely used also in the current Covid 19 period.

These are designed to avoid the establishment of univocal relationships with user groups and hours of use. The space is therefore not only used by the inhabitants of neighbouring houses but is open to external users. The park responds to the well-being and leisure needs of a park, helping to reduce the visual and spatial disorder of the suburban dispersion.

The third case is the Portello Park (Fig. 3) which is located in Milan (Lombardia Region, North of Italy). It was realized in 2011 in the area of the former Alfa Romeo and Lancia. The total area is 385,000 sqm, of which 60,000 sqm of the park. The property is public, it is an area conceded to the municipality. The institutions involved in the creation of the space include public bodies, namely the Municipality of Milan Urban Planning, Private Construction, Agriculture Department – Implementation and Strategic Urban Planning Sector; and private, namely Pirelli Real Estate, Nuova Portello-Auredia and the World Jewellery Centre.

The institution involved in space management is the Municipality of Milan. The funding for the construction of the space are 8,500,000.00 euros (public and private funds)

The urban planning tools of reference is the Variation to the PRG – General Regulator Plan: PII Portello (Integrated intervention plan) stipulated between AUREDIA srl and the Municipality of Milan.

The Urban project was designed by Charles Jencks and Andreas Kipar. As regards, policies activated, The Accordo di Programma – Programme Agreement – 'Portello Project' Integrated Intervention Program (PII) as a variant at the current General Regulator Plan (PRG) had, among the main objectives, the redevelopment of the former Alfa Romeo and former Lancia abandoned areas through the creation of a new large park.

The plan is divided into three large units that create a vast integrated settlement between residential buildings, partly with agreements, commercial and tertiary settlements as well as public services.

The uses concern the creation of equipped areas and squares, services and new residential, commercial and tertiary settlements in order also to reconstruct and reconnect the compact fabric of 19th-century origin of the inner city to the ring road with the more recent city of the peripheral area of the north-west.

Figure 3: Milan, Portello Park (Source: Studio Land).

The entrance to the park is free and the garden is suitable for any type of users. Between the elements that testify the success, the park represents a small corner of tranquillity and silence used for various activities including walking, cycling and parking, and the park is used – respecting the physical distances, also in the current period of Covid 19.

The presence and opinions on social networks include Instagram with the hashtag #parcoportello and Facebook with Alfa Romeo Portello Park, both page and place.

The fourth case is the community gardens of Gardentopia (Fig. 3). These are located in 26 municipalities of Basilicata region, centre of Italy, namely, in: Matera – Agoragri Garden, Garden of MOMenti, White Spikes Garden, L'Erba del Vicinato Garden, Namastè Garden, Matera Nord 2000 Garden, Casino Padula Evolutionary Garden -; Potenza – Horizontal Grove Garden -; community garden of Stigliano, Rionero in Vulture, Barile, Palazzo San Gervasio, Castelsaraceno, Bernalda, Sasso di Castalda, Pietrapertosa, Vaglio, Montemilone, Muro Lucano, Pietragalla, Salandra, Chiaromonte, Vietri di Potenza, Oliveto Lucano, Irsina, Lavello, San Costantino Albanese, Rapone, Maschito, San Mauro Forte, Campomaggiore, and Cirigliano.

The total surface is of 4,800 sqm. Gardentopia is a project promoted by the Matera-Basilicata 2019 Foundation. In 2015, four associations were involved as partners and managers of four community gardens, three in Matera and one in Potenza, in partnership with the Municipalities of Matera and Potenza. Since 2018, 24 other municipalities have been involved as partners and active subjects in the management of community gardens: Stigliano, Rionero in Vulture, Barile, Palazzo San Gervasio, Castelsaraceno, Bernalda, Sasso di Castalda, Pietrapertosa, Vaglio, Montemilone, Muro Lucano, Pietragalla, Salandra, Chiaromonte, Vietri di Potenza, Oliveto Lucano, Irsina, Lavello, San Costantino Albanese, Rapone, Maschito, San Mauro Forte, Campomaggiore and Cirigliano. In each of the 24 municipalities an association is involved, as a partner and manager of the individual community garden, which lead the municipality of reference, for a total of 24 associations involved.

As regards the found, the co-financers of the Gardentopia project are public, namely: European Union, MIbact, FSC, Basilicata Region, Municipality of Matera with 165,000 euros in the 2015–2018 period and 500,000 euros in 2019.

The town planning project of reference is a Regional project. The policies activated in 2015 include: the partnership with the Municipalities of Matera and Potenza for the regeneration of some abandoned areas in their respective municipalities to be transformed into community gardens; Call for Lucanian associations for the regeneration and management of these abandoned areas. Launch of four projects for the regeneration of abandoned areas in community gardens on public areas, managed by four Lucanian associations, namely MOM Association for the Garden of MOMenti, Matera, Agrinetural for the Agoragri garden, and Istituto comprehensive Pascoli for the White Spikes garden in Matera, and UIL Potenza for the horizontal Boschetto garden in Potenza.

The policies activated in 2016–2018 include: the implementation of the activities on the four gardens.

The policies activated in 2019 include: meetings, garden tours, workshops, artistic residences on 32 community gardens throughout the Basilicata region, with 18 international artists coordinated by the curator Pelin Tan. The artists involved include: Luigi Coppola, Italy, Leone Contini, Italy, Errands, Greece, Futurefarmers, USA, Rirkrit Tiravanija, USA/Tainlandia, Martina Muzi, Italy, Volumezero, Italy, Jeanne van Heeswijk, Holland, OrtiAlti, Italy, Michael Leung, Hong Kong, Anton Vidokle, Russia/USA, ABOUT A WORKER, France, Atelier delle Verdure, Italy, Emily Jacir, Mediterranean meson ro studio, Italy, Michela Pasquali, Italy, Nomeda & Gediminas Urbonas, Lithuania/USA, Otobong Nganka, Nigeria/Belgium.

With respect to the type of uses, Gardentopia are community gardens with planting activities and care of the public green, convivial and festive moments. Public events are also held, such as theatre, talks, readings and educational activities. In the Covid 19 period, the activities are carried out with attention to the physical distance.

The elements that testify the success of the case study concern the presence of artists and the tool of art as a connector and element of hybridization between active citizenship and gardens: namely the process is not exclusively based on traditional participation models, or on simple planting activities, but within an artistic production with international artists.

The fifth case study is the Open Laboratory Project which has been realized in Bologna, Emilia Romagna Region (North of Italy) between 2016 and 2018 in a surface of 2,000 sqm. The Institution involved is the Municipality of Bologna and the cost was 3 million euros.

The town planning project of reference is the municipality Urban Redevelopment Program. The policies which have been activated concern as follows. The spaces are all connected each other through a covered path obtained by reorganizing the old underpasses and using the square of the Sala Borsa and the courtyards of Palazzo d'Accursio. The new public space is a place of connection, which is contemporary, comfortable and usable in any climatic condition by citizens and tourists.

The *containers* are networked with each other through appropriately equipped spaces with a view to creating a single 'open laboratory' devoted to the interactive use of cultural heritage and creative collaboration between citizens, administration, associations and businesses.

Figure 4: Gardentopia gardens (Photo credits: Digital Light House 1-2-560x420).

The basic idea is that this public space constitutes a meeting and socialization place, but also a space for technical laboratories and meeting rooms.

The different Labs Spaces are in fact places specially equipped and connected to each other, with a strong coordinated image. They are spaces suitable for welcoming the public with the aim of making information and activities easily accessible and experimenting with technologies and software, with tables for collaborative work and tools for presenting information, spaces to manage moments of aggregation and spaces for meetings and meetings, audio-video equipment for amplification and streaming of meetings and videoconferences.

The intention is to intertwine the production of innovative intangible services and offer consolidated cultural services (the library, exhibition venues, cinema).

The elements which testify the success include: the spaces are frequently used by people of all ages and for different uses and, thanks to the covered path, they are also used on days with unfavourable climatic conditions. Also in the current Covid period the space is used, respecting the physical distances.

The presence on social media concerns the Instagram page with1,224 followers, the Facebook page with 9,250 followers and the twitter page with 11,700 followers.

The last case is Matteotti Square in Catanzaro, Calabria Region (Fig. 5). The first project was realized in 1991, while in 2015 the restoration and completion of the square were carried out.

The total surface is 1.00 ha while the Institution involved is the Municipality of Catanzaro. With respect to the urban project, this first was realized by Franco Zagari, Ferdinando

Figure 5: Piazza Matteotti, Catanzaro, detail, (Source: Photo by Franco Zagari).

Gabellini, Enzo Amantea and Antonio Uccello; the restoration and completion of the square were realized by Franco Zagari, Ferdinando Gabellini, Giovanni Laganà and Domenico Avati.

The funds are constituted by the European funding for the restoration and completion of the square, namely 233 thousand euros.

As regards the policies which have been activated and uses, the square constitutes a large agora with a strong public image that restores harmony and balance to the entire urban context where the space is located. The limitation of vehicular traffic has allowed the use of the square to prevail as a place for people, for socialization, aggregation, parking, observation.

There are narrative themes, such as the name and motto of the city, and more purely celebratory themes that consolidate the relationship of this place with the surrounding context and the city.

The permanent and temporary works of art in the square aim to promote a vocation of the city towards contemporary art.

The elements that testify to the success of the case study can be summarized as follows. A strategic area was created with this garden, considered the bridgehead of the historic centre, divided into four sections: the historic garden, the Vasely promenade, the new Piazza Rotella and the Piazzetta del Cavatore.

The idea that came to fruition was to create an urban space for socialization and a space with a naturalistic-environmental matrix completely integrated into the surrounding landscape. A contemporary public space where safety and hospitality requirements represent two fundamental and distinctive factors.

Finally, the presence on social media and liking on social media concerns Instagram, namely the hastagh # piazzamatteotticatanzaro, with 13 posts. In the current Covid period the space is used respecting the physical distances [13].

4 OBSERVATION AND CONCLUSION

The paper presented a study carried out in the framework of the Ismed-CNR research, INU Community Public Space and Urban Maestro Horizon 2020 project. The researches have a common object – the main topic of this paper – to collect best practices of public space in Italy, starting from the Charter of Public Space which was adopted during the second Biennial of Public Space, held in Rome in 2013, and, contemporaneously, to verify its current validity.

With the database which was used for the case studies, it is possible to collect the information, images and planimetries useful both in the phases of design and realization of a public space, and in the management one. Information relative to the success of the space and its presence on the social networks are also inserted. The data are collected by different sources, including information by the professionals or technicians who realized the spaces, internet, bibliographical references and on-site visits. Thanks to the flexibility of the database, this was slightly adapted to allow the collections of elements useful to comprehend changes of the spaces in this Covid 19 phase.

The chosen case studies are related to one or more principles of the Charter. Indeed, the cases of public spaces which were illustrated in the paper represent emblematic spaces before and during this period, because these were built with logics that can be defined of liveability and healthy, according with different needs of people [19-26]. Now, in the current Covid 19 period some uses were actualized, allowing safer uses for all. For these reasons, some principles of the Charter of Public Spaces [12], needed to be updated, allowing an actualization. In the following, some of the main changes are reported, inserting in Italics the new parts.

6. Public spaces are all places publicly owned or of public use, accessible and enjoyable by all for free and without a profit motive. Each public space has its own spatial, historic, environmental, *identity*, social and economic features.

7. Public spaces are a key element of *individual and social safety and well-being*, the places of a community's collective life, expressions of the diversity of their common natural and cultural richness and a foundation of their identity. The community recognizes itself in its public places and pursues the improvement of their spatial quality.

16. Every public space should be designed with full consideration for diversity *of different age groups and people abilities.*

21. The urban public space system requires a unitary view capable of bringing out the features to maintain, enhance and communicate. It is therefore advisable for local governments to adopt a specific strategy for public *space networks with different and flexible functions which can welcome people also in pandemic periods.*

25. Design must pay full attention to maintenance and management costs by using simple solutions and materials that are durable, simple, easily replaceable *or modifiable* and climatically adequate.

31. The following can be considered constraints on the creation, management and enjoyment of good public spaces: design choices that ignore *multifunctional and healthy* criteria and structural connections; the absence of wireless networks that can widely support new uses of the public spaces; the absence of directions and references, which may cause a condition of deep disorientation in users of urban space *in both normal and pandemic situations*.

Updating the Charter the principles constitute an actual reference for all who – with different roles – participate in the construction of a more liveable and healthy city.

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CONSTRUCTED WETLANDS IMPLEMENTATION IN KATHMANDU VALLEY, NEPAL

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ABSTRACT
Constructed wetlands can be considered as a strategic nature-based wastewater treatment technology for Nepal, where the discharge of untreated wastewater into rivers, lakes or any other water body is a common practice and where the big wastewater treatment plants are not well functioning or are not sufficiently used. The successful implementation of constructed wetlands in Nepal is conditioned by many factors, which should be considered. Legislation is weak and hygienic standards are low; therefore, wastewater treatment is usually not a priority for city governments and private or public institutions, as well as for communities themselves. Under these circumstances, it is not an exception that it might be difficult to convince people to pay for constructed wetlands implementation and maintenance. Our paper discusses conditions influencing the applicability of constructed wetlands in the Kathmandu Valley, Nepal, by empirically analysing the best and bad practices of their application. The focus is paid to present the social situation and history of analysed communities and organisations. Implementation of constructed wetlands for schools is discussed as a special case, as well as the change of the communities' approach towards constructed wetlands' importance, as it appeared during the pandemic situation of COVID-19 in 2020.
Keywords: constructed wetlands, Kathmandu Valley, land management, communities, nature-based water treatment solutions, pollution control, Nepal, water resources management.

1 INTRODUCTION

Constructed wetlands are highly efficient in removing organic and insoluble substances. The construction and operation of them are both simple and cost effective, with low energy consumption (if any). In Europe, constructed wetlands are widely used as an effective, nature-based technology for municipal wastewater treatment both in cities and in rural areas. Even though this technology has all the attributes of a success story – relatively low investment costs and simple operation – its successful transfer to developing countries is not uncomplicated. The main reason for this is the social and cultural differences in these target countries.

In Nepal, the most suitable location for the operation of constructed wetlands is the Kathmandu Valley, where the population is concentrated in three big cities (Kathmandu, Lalitpur and Bhaktapur) with very varying conditions of living and wastewater management practices. The constructed wetlands could be, here, considered for the local solutions and support of the wastewater management practices out of reach of the big Wastewater Treatment Plants at Kodku (Patan), Sallaghari and Hanumanghat (Bhaktapur), Dhobighat (Kathmandu) and Guyesheshowri (Kathmandu), managed by the Government of Nepal via The Kathmandu Valley Wastewater Management Project [1], [2]. The constructed wetlands could be welcomed to provide sustainable wastewater treatment here for a number of households in areas where water retention at the landscape is needed, the groundwater level is continuously declining and the local hydrogeological situation is favourable for the water infiltration.

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The idea of our research in Kathmandu Valley, as well as this paper, is to review the recent situation of the constructed wetlands in the area. Next, find the circumstances that are influencing wetlands functioning and define the important issues for their successful operation and maintenance.

2 CONSTRUCTED WETLANDS AND THEIR VEGETATION COVER IN NEPAL

Constructed wetlands is a biological wastewater treatment technology designed to mimic processes found in natural wetland ecosystems. These systems use wetland plants, soils and their associated micro-organisms to remove contaminants from wastewater [3].

There are two main directions of flow in the subsurface flow wetlands: horizontal flow and vertical flow, both of which have certain advantages and limitations. By combining them, we get a hybrid system that complements each other [4]. In horizontal flow wetlands, the wastewater flows from the inlet in the bed to the outlet of the bed in a horizontal path. As the wastewater moves slowly through the porous substrate, it encounters anaerobic, aerobic and anoxic zones. For Nepal, the horizontal flow constructed wetlands are easier to be maintained successfully; however, the hybrid system could be better functioning in the developed areas in the cities, with limited space, e.g., for private houses or schools.

In addition to the right arrangement, proper vegetation cover that fits into local climate conditions is also crucial for constructed wetlands. In Nepal, we encountered several widely used plants, which were selected based on their presence in the proximity of the implementation site and, of course, also based on their capacity to eliminate water contamination. These especially included calamus, reed beds and hyacinth.

All these vegetation species were documented by us during our field survey in Nepal. Reed beds were found to be most widespread, as this plant is common in the Kathmandu Valley and highly suitable for constructed wetlands because it can be procured at a low cost. The only problem we found in using this plant was that it is not always timely cut and kept in an effective condition; it was usually found overgrown and dry, with limited performance, as, e.g., in the case of the constructed wetland in the Namo Budha tourist resort. Hyacinths were found only in two cases, once in a non-functioning wetland in Kirtipur and once at a private home, where hyacinths were also part of the garden ornamental planting. Calamus is very common in the Lalitpur area; therefore, it was also used for the functional constructed wetland in Dhapakel. However, according to the oral testimony by Ms. Sarala Budhathoki (see Fig. 1), who is in charge of the wetland maintenance, calamus is not entirely suitable for this use due to its medicinal qualities: local people pluck the calamus plants to make herbal infusions and ointments. On the one hand, this reduces the presence of the plant in the wetland and, on the other hand, such calamus plants (as, e.g., in the case of Dhapakel; see Fig. 2) are not suitable for medicinal uses as they may accumulate contaminants from the wastewater being treated.

In constructed wetlands, the vegetation cover performs various important functions that may differ depending on the type of constructed wetland. However, plants in the constructed wetland help decompose and remove insoluble as well as soluble substances mainly of organic origin from wastewater. This takes place both directly (through absorption) and indirectly (e.g., by creating conditions for biofilm growth). The plants also play a mechanical role: plant parts, particularly those found above ground, act as a certain kind of barrier that may affect wind speed, thereby altering the microclimate to some degree. In wintertime, plant residuals on wetland surface may act as an insulation layer [5].

Wetland plants are capable of absorbing some substances from wastewater – nutrients (such as nitrogen and phosphorus), which are then used for the plants' own benefit. Thus,

nitrogen and phosphorus removal from wastewater passing through the plant section of the constructed wetland takes place.

For several biological processes and chemical reactions taking place in constructed wetlands, sufficient oxygen supply is necessary, which supports the existence of aerobic bacteria and thereby also the elimination of biological contaminants. The microorganisms assisting in wastewater purification are mostly bound to the roots of the wetland plants, where they are indispensable for an active nitrification and denitrification process. Nitrification is defined as the biological oxidation of ammonia to nitrates through an intermediate level represented by nitrites. This reaction takes place in the aerobic layer of the soil or in the vicinity of the plants' root systems and requires aerobic conditions [6]. The rate of the nitrification process typically depends on the supply of ammonia nitrogen in the oxygenated zones in the vicinity of the roots, size of these zones, pH, temperature, the presence of nitrifying bacteria and water alkalinity. During nitrification in constructed wetlands, about 4.3 mg of oxygen is consumed per 1 mg of ammonia nitrogen, while hydrogen ions are released, bringing about the acidification of water [7].

Denitrification is a process, through which nitrates are broken down to gaseous nitrogen (or nitrous oxide) and ammonia by bacterial action. Unlike nitrification, denitrification takes place in anoxic conditions (i.e., in the absence of oxygen). During this process, hydroxide ions are released, which means that the water becomes more alkaline.

3 MAINTENANCE PRACTICES OF THE CONSTRUCTED WETLANDS IN NEPAL

Even though constructed wetlands have proven effective for treating different kinds of wastewater, there are still some challenges in the promotion of them. Despite constructed wetlands being a low-cost technology, it might be difficult to convince people to take basic care about the constructed wetlands and pay to treat their wastewater rather than just discharging it into the river (as there is no legislation and penalties to 'convince' them) [8].

Paradoxically, the COVID-19 pandemic in 2020 has helped to promote the benefits of constructed wetlands, as communities fear the spread of the virus through wastewater, and household water treated by constructed wetlands is seen as a source of safe water suitable both for farming and for other uses such as irrigation of gardens, laundry and cleaning activities in the household. As part of a questionnaire survey, we found this attitude, e.g., in the case of the Lalithpur constructed wetland on the Dhapakel site. In 2019, i.e., before the pandemic, when the local wetland was constructed and its operation started, the interest of the neighbouring citizens in its importance was scarce. The wetland was established under the supervision of the Chairperson of the ward on the premises of the Municipal Ward Office in Dhapakel using horizontal flow of wastewater through a permeable substrate planted with wetland plants - calamus vegetation. It was designed for wastewater from offices, a nearby located police station and the local community's training centre for about 20–25 people [9].

The water treated by the wetland is drained into a pit and subsequently infiltrated into a shallow aquifer, as this is a sustainable wastewater management solution without creating contamination of the surrounding land. At the same time, this solution will, in the long run, enhance groundwater yield within a larger area of interest. During the year the wetland has been in operation, the information about the purpose of the wetland had spread through the local community and, during a field survey on 17 October 2020, an opinion was officially passed around that the wetland was necessary for obtaining virus-safe (that is COVID-19-safe) water for farming. The wetland is in good shape and is managed by Ms. Sarala Budhathoki, Social Mobilizer of Ward Office, living next to the ward office. During

Figure 1: Ms. Sarala Budhathoki in front of the Dhapakel constructed wetland.

Figure 2: Dhapakel constructed wetland in October 2020.

a conversation, she clearly articulated the new approach: 'If we could establish this system of constructed wetlands in the community and household level, water can be used for the irrigation. And this water is safer and less likely to be catalyst for spreading of virus. So that farmers do not need to rely on other sources of water where the high chance of spreading of virus through water exists.'

Before the COVID-19 pandemic, the communities' interest in keeping the constructed wetlands in good shape on their own was far from being a reality. Even though the maintenance of constructed wetlands and their surroundings is simple and not energy consuming, requiring only minimum expenses (such as for obtaining or purchasing the necessary material for their construction, cleaning of the wetland filters and sand every 7 to 10 years, as is necessary, modification of the wetland plants and their exchange or, if needed, occasional sampling of water released from the wetlands to monitor its quality), it is not common. In case these expenses (or the salary of the wetland manager) were not covered from the community sources or subsidies or if no clear economic benefits were associated with wetland maintenance (such as the use of biogas at sites with a pond for biological pre-treatment where digestion of organic waste takes place prior to entering the wetland), the interest in wetland maintenance was declining up to the point of vanishing completely (as was observed in the case of the Kirtipur community; please see the chapter 'Story of the Kirtipur community').

In times of the pandemic, the economic benefits have been outmatched by the fear of the COVID-19 virus. The communities' demand for 'wholesome water without the virus' was the main motivation factor for accepting and maintaining the constructed wetland. The communities are now capable of allocating the necessary funds for the maintenance of the wetland to ensure and oversee its proper operation.

The question is how long this situation is going to last after the COVID-19 pandemic is over.

4 FIELD RESEARCH IN THE KATHMANDU VALLEY

The sociological research was aimed at getting an in-depth understanding of the situation, as well as the factors supposed to influence it. Therefore, a qualitative approach was used. Doing so, we were in line with approaches applied to understand ecosystem services implementation strategies in general and constructed wetlands in particular [10–15]. The sociological

field research was based primarily on the application of qualitative methods. Empirical data were gathered by the use of semi-standardized interviews with particular stakeholders. In the situation of the absence of an effective state regulatory framework in Nepal [16–18], local socio-economic conditions were considered the most important factor for the successful implementation of constructed wetlands *in situ*. Therefore, the interviews aimed to reveal the socio-economic and cultural situations in particular spots, as well as the role of particular stakeholders in the process of constructed wetland building and operating or declining.

A particular constructed wetland associating all the above-mentioned types of stakeholders was defined as the main unit of analysis. The situation *(the particular constructed wetland)* was considered the basic unit of the analysis, in which three principal actors directly participated:

- users of constructed wetlands *(communities, institutions* and *private houses)*
- local authorities setting the political context *(mayor offices* and *chairpersons of pertinent commissions)* and
- NGOs, local to international, channelling financial sources and supervising the building and operation of constructed wetlands.

Sixty constructed wetlands situated in the Kathmandu valley, mentioned on the list produced by the Environment and Public Health Organization (ENPHO) [19] and in the other sources, were used as the point of departure in identifying the sample. When checking the reality, however, we were able to find only 23 of them. All were included in the sample. The sample represented a relatively wide variety of situations, as can be seen in Table 1.

The field campaign – visit of particular constructed wetlands – was realised by the authors in September 2019. There were three interviewers in the team working jointly, two Czech and one Nepali who served as an 'interface' between west science and the local situation, culturally far different from that in Europe. To minimize the danger of information loss or potential misinterpretation of data, the interviews were audio recorded in Nepali (see Fig. 3), transcribed verbatim and subsequently translated into English. To complete the picture, photo documentation was done, as, e.g., in the case of the interview with the Biogas Committee of the Sano Khokana (see Fig. 4). The text was subsequently analysed using thematic analysis.

Table 1: Structure of the sample.

Type of user	**State of the Constructed Wetlands**			
	Functioning	**Partly functioning**	**Not functioning**	**Total**
Schools	1	1	3	**5**
Communities	1	1	3	**5**
Private houses	1	1	1	**3**
Research institutions	2		4	**6**
Hospitals	1		1	**2**
Monastery			1	**1**
Industry	1			**1**
In total	**7**	**3**	**13**	**23**

Figure 3: Sunga Thimi community – the audio recording of the interviews.

Figure 4: Interview with the Biogas Committee of the Sano Khokana constructed wetland.

The questions we asked in the interviews focused on the status of the constructed wetland (if it is functional, semi-functional or not functional) and in the case of the **functional and semi-functional constructed wetlands,** we discussed the following areas:

- Who owns the constructed wetland and for whom it was constructed?
- Socio-economic description of the community/settlement/household (*in terms of caste, ethnic group* and *economic class),* length of stay at the spot *(permanent – immigrants)* and number of users
- Which specific technology was used for the implementation of the constructed wetlands at the site? Why was this specific technology chosen or, if this is the case, who had recommended it and why? In the Kathmandu Valley, there are two main organisations dealing with the implementation of constructed wetlands (the ENPHO [19], who has been pioneering the implementation of constructed wetlands in Nepal, in cooperation with the Austrian University of Bodenkultur, Vienna, since 1997 [20], and Lumanti, a non-profit making organization dedicated to the alleviation of poverty in Nepal through the improvement of shelter condition). Both of them have their own ways, financial resources and intentions as to why and how to promote constructed wetlands. In the case of ENPHO, these include environment protection support, municipal wastewater treatment and the supply of 'healthy' water for households and permanent communities. Lumanti, on the other hand, typically builds constructed wetlands as part of new housing units for families in need, which, after they settle in, constitute an entirely new community with their neighbours.
- Who takes care or is responsible for the constructed wetland being operational *(what 'responsible' means in practical terms and what activities are expected to be 'responsible'. Do they have a management/user committee? If yes, how it was formed and what are its main activities/responsibilities related to the constructed wetland? Do they manage the constructed wetland as well financially?)*?
- Involved end users and financial source (*who initiated wetland construction and why, what financial source were used and why these particular ones, etc.*)
- Community management aspects – do they want to keep the constructed wetland operational and why (*importance of constructed wetlands for them; advantages compared to other solutions of wastewater treatment, including zero treatment)*? Do they know about/are in contact with other cases where the technology of constructed wetlands is/was used as a technology for wastewater treatment?

- Major problems/challenges related to the constructed wetland operation, if any *(in the past, at present or expected).* What would they like to change, and could they do it themselves or is an external assistance expected/needed?
- How do they see the future of their constructed wetland system? How do you share your good and bad experiences with other areas/people if at all?

In the case of the **non-functional constructed wetland,** we discussed the following areas:

- Why the constructed wetland stopped working? What were the reasons *(low efficiency of applied technology, difficulties in maintaining it/poor maintaining, economy or any other reason, including social and cultural/ethnical barriers)*?
- What kind of technology for the treatment of wastewater they use instead, if any *(including no-treatment)?* Is the newly applied technology better and in which aspects?
- Is there any chance to put the constructed wetland into operation again? If yes, under which conditions/circumstances? Do they plan to do it?

The results suggest that it is the motivation (or lack of it) of users to have the constructed wetland that represents the major factor responsible for the implementation of this technology. Relatedly, community involvement and clearly defined personal responsibility for maintaining the wetland decide as a rule on keeping the wetland in operation in the long run. In this respect, the situation in Nepal does not differ profoundly from the situation in the Czech Republic.

Lack of necessary land for constructed wetland implementation is another challenge in Kathmandu city, where the private household owners are interested in sustainable and economically feasible solutions to keep the water for their use. Many of the households have land just for their building construction and no space for the constructed wetland organisation.

The consideration of constructed wetlands as a low maintenance technology sometimes leads to carelessness during operation and maintenance [16]. However, maybe the situation will change after the pandemic of COVID-19?

5 STORY OF THE KIRTIPUR COMMUNITY

The Kirtipur community in Kathmandu is formed by the 44 poor internally displaced families from other areas after road-widening activities. They are living in small houses built by the Lumanti non-profit organization as a complex including a constructed wetland and a rain harvesting system.

As part of the field survey, we visited the constructed wetland built for the needs of the Kirtipur community both in 2018 and 2019. On both occasions, we found that the wetland was functioning to a very limited degree. The constructed wetland system on this site is composed of two horizontal artificial wetlands: an upper (bigger) wetland and a lower (smaller) wetland, from which water flows freely into a ditch used for the irrigation of the farmland, which, however, is not owned by the community.

Prior to entering the wetlands, wastewater flows into a settling basin where mechanical and biological contaminants are separated and biogas is produced. In 2018, biogas was used by two households of community members who were voluntarily taking care of the constructed wetland operation, though to a limited degree permitted by their religious belief. In fact, the Kirtipur community members belong to a caste that is forbidden from touching waste. As a result, they are not allowed to clean the septic tank and waste produced by the mechanical wastewater pre-treatment at the inlet into the constructed wetland system. The contamination is building up in the basin, compromising the performance of the upper wetland. The waste from the pre-treatment basin may only be hauled away by an external subcontractor, whose

services need to be paid for. This does not suit the community, so they prefer to leave the waste in place. The biogas production has also been affected by the poor management of the separation basin. In 2019, biogas was not used anymore and, therefore, this motivation factor for the constructed wetland maintenance manager disappeared as well. During the 2019 visit, no one was found to claim direct responsibility for the wetland maintenance.

The bigger constructed wetland is situated at the centre of the community square (see Figs. 5 and 6); the treated water from this wetland flows horizontally into a lower-lying, noodle-shaped wetland in the lower part of the community village. In 2018, due to monsoon rains and clogging, the central wetland had been transformed into a pond, from which only a small number of hyacinths were emerging, while a lot of garbage, food scraps and plastic bags were floating around. In 2019, new gravel was placed in the upper wetland, which, however, did not significantly enhance its performance: there was a single small island of vegetation in the entire 'wetland', while the other plants had nearly disappeared. Water from this area filters by gravity along preferential pathways through the gravel filter into the lower-lying wetland, which has a corresponding amount of reed beds. However, the performance of this wetland is again severely affected by clogging. From this wetland, muddy water with an almost imperceptible smell flows out into the irrigation ditch.

The Lumanti organisation, which built the community village along with the constructed wetland and a biogas plant, apparently underestimated the social situation of families from the Kirtipur community. These families are randomly settled together without having previous relationships; thus, the community is new, and this results in their attitude towards the common property. In addition to that, the Kirtipur community members did not participate in the construction of the constructed wetland. They received it for free along with the community membership (which was obtained for a financial contribution for being allowed to live in a small house within the community).

In Kathmandu and its surroundings, Lumanti engages in active protection of the quality of water in the Bagmati River and environmental sustainability. The organisation also assisted in establishing a constructed wetland for the Sano Khokona community that has been living together for a long time. In this case, the initial intention was successfully carried out. The constructed wetland has been operating successfully for more than 15 years, including a biogas plant providing biogas for six households. The whole constructed wetland system is kept functional thanks to the activities of the Biogas Committee, which consists of nine

Figure 5: Kirtipur upper constructed wetland in the September 2018.

Figure 6: Kirtipur upper constructed wetland in the September 2019.

members on a voluntary basis. What is also positive for the sustainability of the system is the fact that the constructed wetland was built using 80% of the funds from the Lumanti non-profit organisation and 20% from the community's own sources in the form of local people's labour. The Biogas Committee members also profit from the biogas production.

This example clearly shows that the motivational component is not to be underestimated in environmental protection as, for the majority of less-educated Nepalese, high-quality environment in itself is not a sufficient reward.

6 THE SPECIAL CASE: SCHOOLS IN THE KATHMANDU VALLEY

In the Kathmandu Valley, a special case of model users are bigger schools, where constructed wetlands mostly work well. As two cases that are different (as to their focus and ways of teaching) and yet similar (in their necessity of making themselves visible and the tendency towards addressing environmental issues), we selected two schools running similar constructed wetlands composed of a sedimentation tank where the separation of the solid and liquid parts takes place, followed by an anaerobic baffled reactor and constructed wetlands with emerged vegetation. Satya Sai Sikshya Sadan School is an academic school with religious tradition. The first of the series of Sri Sathya Sai Schools was founded by Master Sai Baba in India in 1968; in the same tradition of the five pillars of Truth, Right-conduct, Peace, Love and Non-violence, the school at Tokha in Kathmandu was established in 2014. At the school, about 550 residents, including teachers and personnel, are living, out of which there are about 400 schoolchildren from 56 districts of Nepal. There is no sewerage in the school. As a result, a decision was made during the construction of the school that, in accordance with its spiritual and environmental tradition, constructed wetlands would be set up for wastewater treatment, serving at the same time as a technology for infiltration of the treated water into the shallow aquifer to enhance the recharge of the exploitable groundwater in a broader area. The constructed wetland system connected with a rainwater harvesting system on the school premises is also used for educational purposes both for their own students and as a model for other schools and institutions. Financing of the constructed wetlands (their construction and maintenance) is done from the school's own local funds (particularly school fees), while the laboratories of the ENPHO organisation help with water quality monitoring. The constructed wetlands are fully functional there (see Fig. 7), and the school is proud of

Figure 7: Satya Sai Sikshya Sadan school – the well-functioning constructed wetland, September 2019.

Figure 8: Shuvatara school semi-functioning constructed wetland, September 2018.

them. The constructed wetlands on the Satya Sai Sikshya Sadan school premises were presented to us by the school principal himself, who is also its highest religious representative. The school motto is: 'Water is life!'.

Another example of schools where wastewater from bathrooms, toilets and the kitchen are released into constructed wetlands is Shuvatara International School (private boarding high school) in Lalitpur (see Fig. 8). It is a school for young people from wealthy families (attended by about 700 students) where constructed wetlands and, generally, environmental education are regarded as a token of good quality, increasing the school's prestige. The proprietor of the school is one of the richest businesspeople in Kathmandu who, among other things, owns a chain of restaurants and snack bars where only deaf-mute staff are employed. The constructed wetlands on the school premises are in good shape. Moreover, there is an appointed person responsible for the maintenance and monitoring of the treated water quality. Even though the constructed wetlands on the premises were working only partially, as part of them was being renovated, the water released from them was clear and absolutely without smell. This treated water was then drained by a ditch running along the school premises to the close-by agricultural fields. Prestigious schools in Nepal are a good environment for the construction and operation of constructed wetlands and, in this context, maybe generally held up as an example. It is in the interest of the schools to maintain their constructed wetlands because they are part of their image and the reason why parents – thanks to environmental education – choose them for their children. However, it still needs to be examined how school managements have dealt with the limited operation of the constructed wetlands and whether the constructed wetlands designed for several hundreds of students and staff are still in operation after unexpected cases of lockdown, as in 2020–2021, during the COVID-19 pandemic when schools, with very short interruptions, were closed by state orders from spring 2020 until 4 January 2021. During the lockdown, the schools were not in operation and wastewater was not produced. Therefore, it is crucial to determine whether the constructed wetlands have not been damaged due to insufficient horizontal flow and how school managers have dealt with this situation.

Another suitable type of site that is specific for Nepal (but is not at the centre of interest of this paper) is the implementation of constructed wetlands and generally nature-based technologies at the centres for spiritual practice and yoga for foreign clients and tourist resorts in general, where it is desirable to demonstrate a connection to nature (as an example of partial success, the Namo Budha Resort and Chandra Ban Eco Resort can be mentioned, see Figs. 9 and 10).

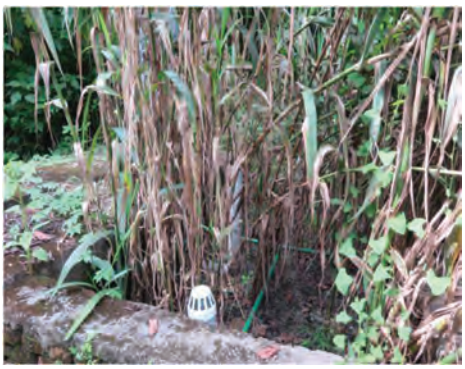

Figure 9: Semi-functioning constructed wetland in the Namo Budha tourist resort, September 2019.

Figure 10: Place of the not well-functioning constructed wetland at Chandra Ban Eco Resort, September 2019.

7 CONCLUSIONS

There is no doubt that constructed wetlands are an important part of water management in the Kathmandu Valley and can – in an environment with lacking state and legislative wastewater management – at least partially meet the demand for 'healthy' water for farming and service purposes within small communities and thus play an active part in environment protection.

In private schools, e.g., the presence of a constructed wetland may enhance the school's reputation, which will reflect in the students' increased interest in studying there and, at the same time, ensure appropriate education of the students in preserving a high-quality environment for life (as an example, a very successful constructed wetland and rainwater harvesting system in the Satya Sai Sikshya Sadan school can be mentioned).

The other highly suitable site for the constructed wetlands building and operation are municipal premises – the success story of Dhapakel could be mentioned. It is very important that the Chairperson and/or the manager of the constructed wetlands is open to innovation and respected by the local communities.

Another suitable type of site that is specific to Nepal is the implementation of constructed wetlands in tourist centres for foreign clients.

The COVID-19 pandemic has paradoxically helped promote constructed wetlands at the level of communities, which previously did not pay much attention to the environmental aspects of household wastewater treatment by nature-based technologies. During the pandemic, economic benefits (such as extra income or source of biogas for those who look after the wetlands), which are usually crucial for long-term wetland management, have been overridden by the fear of the virus and its spread by water. Overnight, the demand for 'healthy water without virus' has become the main motivation for the maintenance of constructed wetlands. Water purified by constructed wetlands is considered safe and used for the irrigation of agricultural crops or gardens by the communities.

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MACHINE LEARNING METEOROLOGICAL NORMALIZATION MODELS FOR TREND ANALYSIS OF AIR QUALITY TIME SERIES

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ABSTRACT
Air pollution is a major environmental cause of morbidity and mortality worldwide, representing a top public health objective, especially in areas interested by the presence of anthropic emissions sources. Correctly assessing how pollutant emissions influence the air quality is, therefore, crucial for the design and/or implementation of effective measures from the public health perspectives. The impact of local emission sources on air quality is strongly modulated by meteorological conditions, which can mask the real trends in the observed pollutant concentrations. However, the confounding effect of meteorology in air quality time series can be accounted for by techniques of meteorological normalisation. In this study, the performances of a meteorological normalisation technique based on machine learning (ML) algorithms were investigated. To these purposes, two ML models (gradient boosted regression (GBM) and random forest (RF)) were developed and subsequently used to calculate meteorologically normalised trends of nitrogen oxide (NO_x) concentrations time series. Both models were trained on daily averaged data of NO_x concentrations and meteorological parameters, as well as on temporal variables; data were acquired, over the 2013–2019 period, in a rural area affected by anthropic sources of air pollutants. Results obtained show that both models are able to explain more than 70% of the variance in the NO_x observed concentrations and that the meteorological normalization technique based on both algorithms represent a robust method to account for the confounding effect of meteorology in air quality time series. Moreover, the GBM/RF ML models allowed to analyse the dependence of the observed concentrations on each explanatory variables used in the models, shedding light on the role of local meteorological processes in the observed pollutant concentrations. This knowledge can help in defining air pollution control strategies that are increasingly effective in preventing and/or mitigating health damage associated with exposure to atmospheric pollution.
Keywords: air pollution, boosted regression trees, machine learning, meteorology, random forest, trend analysis.

1 INTRODUCTION

Air pollution is a major risk factor to human health. According to the World Health Organization (WHO), ambient air pollution causes more than 4 million premature deaths every year worldwide, and more than 90% of the population lives in areas exceeding the WHO guideline limits [1]. Furthermore, air pollution is one of the major factors contributing to climate change, especially in terms of global warming; at the same time, climate change can perturb the long-range transport, chemical processing and local meteorology that influence air pollution [2]. In the European context, Italy presents several criticalities in terms of high-polluted areas [3]; moreover, due to its geographical position at the centre of the Mediterranean area, it is also a 'hot spot' for climate change because of the intense photochemical activity, the crossing of air masses of different origin and the strong anthropogenic pressure [4].

To manage the air quality issues, the environmental or health decision makers need reliable estimates of pollutant concentration levels and related trends as input for decisions. The quantitative assessment of the real trend of pollutant concentrations is complicated by the variability of air pollution due to variations in local and synoptic meteorological conditions and seasonal effects, as well as the non-linear responses between emissions and concentrations

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of air pollutants strongly affected by meteorology over multiple scales in time and space [5]. Therefore, to avoid that weather effects mask the actual trends in the observed pollutant concentrations, the confounding effect of meteorology in air quality time series must be accounted for. Once the weather effects have been removed, further statistical evaluations can be carried out in the resulting air quality time series, obtaining more robust estimation of pollutant trends or more reliable air quality predictions.

The process of accounting for changes in meteorology over time in an air quality time series, which is referred as 'meteorological normalization', can be carried out through several statistical techniques [6]. An emerging approach to meteorological normalization is based on machine-learning (ML) algorithms [7]. It mainly consists of a two-stage process reducing air quality time series variability with statistical modelling: first, an ML model, linking air quality and weather data, at a location of interest is used to predict pollutant concentrations as a function of meteorological parameters [8]. Second, if the model explains an adequate amount of variance in the predicted air quality variable, it can be used under a range of meteorological conditions, with the associate average referred to as meteorological–normalized time series [9].

Among the most popular ML algorithms, those based on decision trees methods, such as gradient boosting regression (GBM) [10] and random forest (RF) [11], are extensively used in the air quality field [12], [13]. Both these algorithms use a set of independent variables (explanatory or predictors variables) and an ensemble of decision trees to make predictions of a variable of interest (target/dependent variable). GBM/RF models are characterized by strong predictive performances and remarkable capability of insights on the relationships between variables. Their increasingly widespread use is due to their ability to model non-linear relationships, to manage qualitative and quantitative variables, to remain robust despite missing data and outliers, to reduce overfitting and to require a limited number of user-defined parameters for model fitting/selection purposes. Furthermore, thanks to the interpretability of the GBM/RF models, it is possible to provide the functional relationships between each predictors and the dependent variable, improving model understanding and trustworthiness.

The aim of this study is to explore the performances of both GBM/RF algorithms as a basis of a meteorological normalization technique by assessing the global accuracy metrics, as well as the interactions between the target and the explanatory variables selected for the models development. Moreover, trend analysis of the normalized air quality time series is also performed to quantitatively assess the changes in the ambient air pollution.

To these purposes, two GBM/RF models were built, validated and subsequently applied to calculate meteorologically normalized air quality time series. Both models were trained on daily averaged data of NO_x and meteorological parameters as well as on time variables; data were acquired, over the 2013–2019 period, in a semi-rural area affected by anthropic sources of air pollutants. A comparison between GBM and RF models was made on the basis of several statistical indicators [14]. Trend analysis was carried out on the normalized NO_x concentrations using the Theil–Sen regression technique [15]. Finally, the abilities of both models in ranking, visualizing and predicting the relationship between NO_x concentrations and its driving factors were analysed and graphically illustrated.

The paper is structured as follows: Section 2 describes the study area, the data used and the main steps adopted for the meteorological normalization procedure based on the GBM and RF models. A comparison between GBM and RF models' predictive performances, as well as the results obtained with the meteorological normalization procedure and the subsequent trend analysis, are presented in Section 3. It also includes a description of the outputs of the GBM and RF models. Finally, Section 4 summarizes the main findings of this work.

2 MATERIALS AND METHODS

2.1 Study area

The study area is the Agri Valley, located in the South-West part of the Basilicata Region (Southern Italy) (Fig. 1). Moreover, the site location is at the centre of the Mediterranean area, one of the most responsive regions to climate change.

Starting from the early 1990s, the largest on-shore western European reservoir of crude oil and gas in a populated area and an oil pre-treatment plant (identified as Centro Olio Val d'Agri – hereafter COVA) are operating in the valley [16]. The COVA plant determines emissions of gases and particulates, which can affect the air quality and potentially pose health risks for the population living in the area. Continuous concentration measurements of regulated pollutants and of several pollutants specifically related to oil/gas extraction activities are provided by an air quality control network, consisting of five monitoring stations. At the stations are also measured the following meteorological parameters: temperature (T), atmospheric pressure (P), relative humidity (RH), solar radiation (SR), wind direction (wd) and wind speed (ws). The Environmental Protection Agency of the Basilicata Region (ARPAB), managing the network, validates and makes public these data. More details about the methods and the instrumentation used for the measurements can be found elsewhere [17]. For the purpose of this work, data were obtained from the monitoring station closest to the COVA plant, named Viggiano (VZI, 40°18'50''N, 15°54'16''E, 603 m a.s.l.), categorized as an industrial station in a rural area. It is located at about 350 m from the industrial site and about 1000 m from a national road (SS598) characterized by a moderate volume of traffic produced by cars and heavy vehicles.

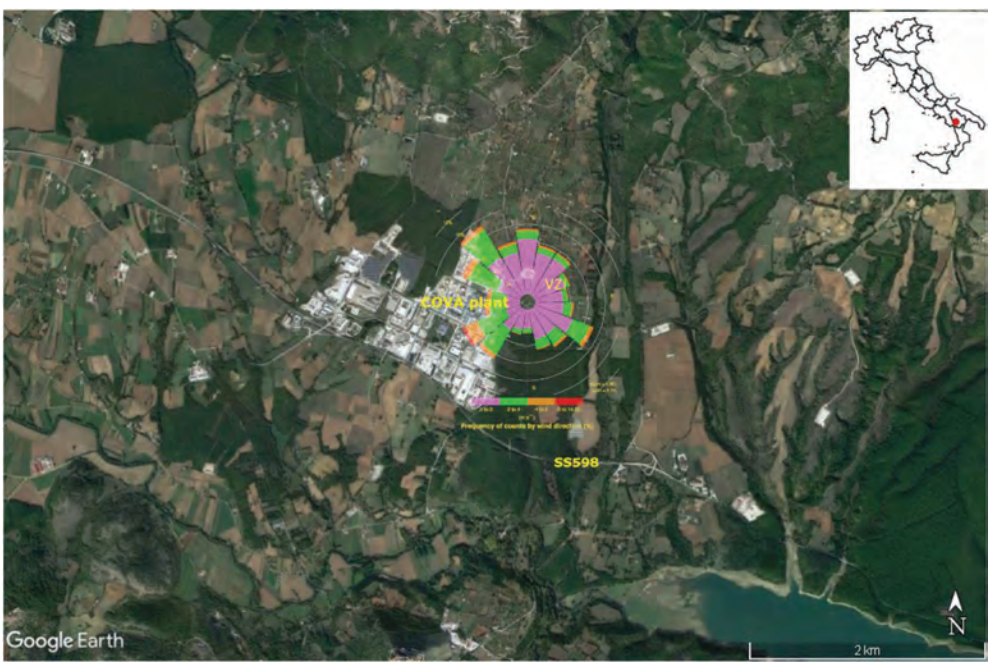

Figure 1: Map of the area: the VZI monitoring site, the COVA plant and the wind rose based on hourly data at the VZI station over the study period (2013–2019).

2.2 Data preparedness

The meteorological normalization procedure was applied at the NO_x concentrations time series, which are key air pollutants also playing an important role in tropospheric chemistry as precursors of tropospheric ozone and secondary aerosols [18]. Being predominantly emitted during fuel combustion, such as by vehicle engines, industry processes and domestic heating, NO_x can be considered as an indicator of the anthropic emissive sources existing in the examined area, which mainly consist in the conveyed emissions produced by the COVA plant and in the local traffic sources. Therefore, to form the whole data set used for the GBM/RF models development, hourly data of NO_x concentrations together with the meteorological variables P, RH, T, ws and wd were downloaded from the official website of ARPAB [19] and combined together. Overall, a data set consisting of more than 59000 observations covering the 2013–2019 period was set up. The time series of all predictors considered respected the required 75% proportion of valid data. The daily average of data was used as input to the model; this time resolution balances the need to preserve the pattern of data at a temporal scale consistent with the examined phenomena and the need to reduce the noisy data and the computational resource demand. Subsequently, a range of other variables was added to the ML models development. These are the day of the week (weekday), the Julian day, i.e., number of days of 1 January (Jday) and the date Unix (trend), i.e., the number of seconds since 1 January 1970; they can be interpreted as proxy for local traffic sources or to account for seasonal and long-term variability, respectively. The day of the week was a categorical variable, while all others were numeric; moreover, all variables were used within their response scale. All data loading, processing, statistical analysis and modelling were accomplished in the R software environment (version 4.1.0; Foundation for Statistical Computing, Vienna, Austria) and its packages.

3 METHODOLOGICAL APPROACH

The methodological approach adopted in the present study consists of the following main steps. First, GBM/RF models were developed, and their performances were estimated and compared. Second, the meteorological normalization was carried out on the predicted NO_x concentrations by each model, and the relevant trend analysis was subsequently performed. Finally, the interpretability of the models was evaluated to ensure their plausibility and reliability.

3.1 GBM/RF models development

Theoretical insights of both GBM and RF models' development are beyond the scope of the present paper and can be found in [10] and [11], respectively. Here, it intends to recall only those concepts that are necessary for the understanding of what will be discussed later. Both GBM and RF are ensemble models that have been developed to optimize predictive performance by training multiple 'weak learners' and merging their results to build a 'strong learner'. GBM is a step-wise, additive-type model that sequentially fits new tree-based models. Each fitted model at every step attempts to compensate for the shortcomings of the previous fitted models. The final model aggregates the results from each step and a strong learner is achieved. RF generates a large number of individual models in a parallel way. In the training procedure, each tree is built based on a random subset of the original data (with replacement). In addition, a randomly selected subset of predictors is chosen for each built

tree, and the RF predictions are the averaged output of all aggregations. To build both GBM/RF models, the whole observed dataset was randomly partitioned into a training dataset (80% of the observations) and a testing dataset (20% of the observations) used for model performance evaluation. The best model for each of the two ML techniques was obtained by tuning the relative hyper-parameters. For the GBM model, this process was carried out using the *gbm* R package [20] on a grid of possible values, while the *tuneRanger* R package [21] was used for RF model tuning. In both cases, the best combination of hyper-parameters, based on R^2 metric, was chosen to build the optimal models on the training dataset. For GBM, the best combination was: learning rate = 0.005, tree complexity = 5, bag fraction = 0.5; number of trees = 5,450. For RF: number of variables sampled to determine each split = 4, minimum number of terminal nodes = 2; number of trees = 1000.

Prediction performances of both models were evaluated by comparing predicted and observed NO_x concentration values using a range of statistical indicators. The coefficient of determination (R^2), the index of agreement (IoA), the mean bias error (MBE), the mean absolute error (MAE) and the root mean square error (RMSE) are used in this work. The relevant equations are provided in Appendix A. High accuracy (R^2 and IoA close to 1) and minimal errors (MBE, MAE and RMSE close to 0) are the desired performances for an optimal prediction model.

3.2 Meteorological normalization procedure and trend analysis

The procedure adopted for the meteorological normalization has been proposed in [22], which modified that originally proposed in [7] and consists in normalizing the NO_x concentrations with the GBM/RF model, resampling the meteorological explanatory variables from the whole study period. In this way, the normalization process preserves the emission changes in the normalized concentrations. For both models, this process was repeated 300 times after all the predictions were aggregated using the arithmetic mean to obtain the meteorological normalized concentration. The benefit of this approach is that the trend calculated in this way will more closely relate to emission changes rather than changes due to meteorological effects. The meteorological normalization of GBM model was conducted using the *deweather* R package [23] modified to use the optimized hyper-parameters values, with the underlying *gbm* R package; for the RF model, the meteorological normalization was carried out using the *rmweather* R package [7], with the underlying *ranger* R package.

Once normalized, the NO_x concentrations time series were object of further statistical analysis. The Theil–Sen regression technique was used to calculate the direction of a trend in the normalized concentrations over time. The Theil–Sen method assesses the median slope of all possible slopes that may occur between the data points. It is regarded as more suitable than the linear-regression method, as it gives more accurate confidence intervals with non-normal distributed data and it is not affected as much by outliers. All the regression parameters, among which is the *p*-value for the slope, are estimated through bootstrap resampling. In our calculations, the trends were based on monthly averages, and they were adjusted for seasonal variations, as these can have a significant effect on monthly data.

3.3 GBM/RF models interpretability

Among the undoubted advantages of the decision tree ML models are several tools allowing to interpret the GBM/RF models, enhancing their understanding and trustworthiness. These

tools are the relative importance of predictors and the partial dependence plots between variables. For RF models, the variable importance measures the impact of each feature on the accuracy of the model [11]. For GBM models, the variable importance is determined by a variable's average relative influence across all trees generated by the GBM algorithm [10]. The partial plots illustrate the effect of each explanatory variables on the dependent variable after accounting for the average effects of all other variables; in this way, the plausibility and reliability of the model can be verified.

4 RESULTS AND DISCUSSIONS

4.1 Statistical analysis

The descriptive statistics of each variable used in the model are summarized in Table 1.

Time series analysis of air pollution metrics for the regulated pollutants measured at the VZI station showed a general compliance with the limits set by the existing national [24] and European legislation [25], [26]. As far as the climate is concerned, the cold and rainy winters, as well as cool summers with frequent rainfall [27], typically registered in the area, define an area at sub-continental climate. During the study period, the mean temperature was 13.78 °C, the mean relative humidity was 71.1%, while pressure was rather static. The mean value of ws was 1.8 ms^{-1} with the higher values generally measured during daytime. As shown by the wind rose in Fig. 1, the prevailing wind direction was from the SW–NW sector.

4..2 Models comparison

The GBM/RF models took the form shown by equation 1:

$$NO_x = gbm\,/\,rf\left(T, H, ws, wd, P, jday, weekday, trend\right), \tag{1}$$

where *gbm/rf* were the functions implementing the GBM and RF technique in the R software environment. The resulting predictive performances and behaviour of both models were compared through the statistical indicators shown in Table 2. The results suggest that both models were highly predictive based on the range of R^2 values from 0.73 (RF) to 0.76 (GBM). The R^2 values suggest that GBM/RF models can explain more than 70% of the total NO_x variability. Both models showed very similar performances both in terms of minimal errors based on the average values of MBE, MAE and RMSE and in terms of prediction accuracy.

Table 1: Statistical summary of hourly data of NO_x and meteorological parameters registered at the VZI monitoring station from January 2013 to December 2019. m.u. = measurement unit.

Parameter	m.u.	Min	Max	Mean	Median
NO_x	µg/m³	0.00	186.06	16.63	11.17
RH	%	5.68	100.00	71.31	74.50
ws	ms^{-1}	0.00	14.08	1.80	1.38
T	°C	-10.90	41.69	13.78	13.10
P	hPa	872.00	971.00	945.20	945.30

Table 2: Statistical indicators of the GBM and RF models performances for the testing data set. Legend: R^2 = coefficient of determination, MBE = mean bias error, MAE = mean absolute error, RMSE = root men square error and IoA = index of agreement.

NO_x	R^2	MBE [μg/m³]	MAE [μg/m³]	RMSE [μg/m³]	IoA
GBM	0.76	−0.45	3.72	5.52	0.76
RF	0.73	−0.09	3.53	5.39	0.76

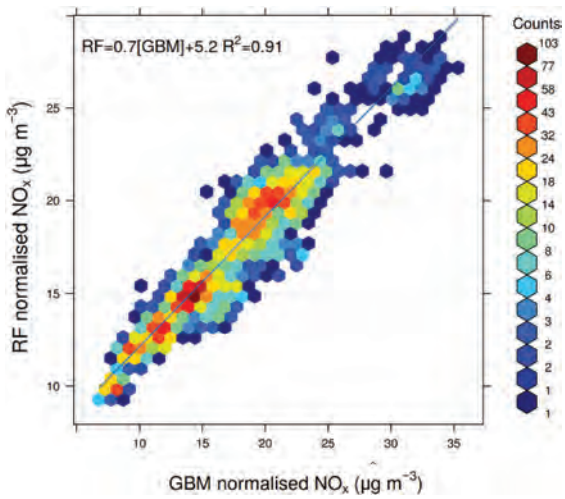

Figure 2: Scatter plot of the GBM *vs*. RF normalized NO_x concentrations.

As shown in Fig. 2, the NO_x-normalized trends from both models agree very well with each other, R^2 =0.91, confirming the substantial similarity in the predictive ability.

4.3 Meteorological normalization and trend analysis

The observed daily concentrations of NO_x were compared with the normalized concentrations predicted with both GBM and RF models (Fig. 3). The meteorological normalized signal highlights the trends of the NO_x concentrations with respect to the observed data. It is worth noting a relevant decrease around February–March 2016 that is consistent with the reduced emissive activity of the COVA plant due to a general plant shutdown for judicial investigations to which the plant was subjected, approximately from end of March to early August 2016, and to the consequent lower traffic regime around the plant.

Trend analysis of the normalized NO_x concentrations, performed with the Theil–Sen method, shows a statistically significant decreasing pattern: −0.66 [−1.17, −0.34] μg m³ year¹ in GBM and −0.62 [−0.99, −0.37] μg m³ year¹ in RF model, respectively, where the square bracket represents the 95% confidence intervals. This is in line with the general decreasing trend of nitrogen oxides registered over the whole national territory. The observed data give about the same trend (−0.66 [−1.13, −0.27] μg m³ year¹) probably supporting the hypothesis

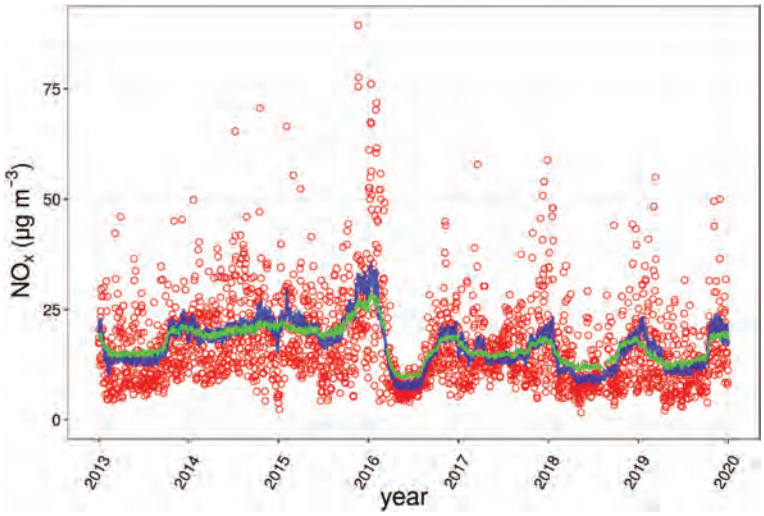

Figure 3: GBM and RF normalized NO_x concentrations (blue and green lines respectively). Red dots represent the daily averages of the observed NO_x concentrations.

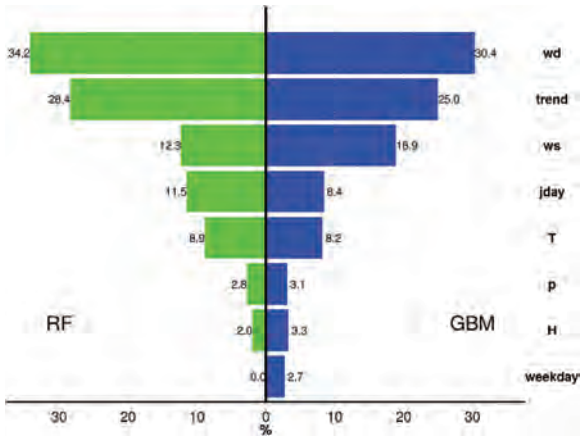

Figure 4: Relative importance of the explanatory variables in the GBM and RF models.

that the change in local sources emissions could overcome the effects of local meteorology in the observed NO_x variability.

4.4 Models interpretability

The relative importance of predictors and the partial dependence plots can be used to shed light on the role of single predictors on the NO_x concentrations variability. In Fig. 4, it is shown that the relative importance of the predictors is normalized to 100% and in a descending order.

According to the obtained results, both models indicate in wind direction the most important contribution to NO_x variability, closely followed by trend and, to a lesser extent, by ws and Jday. The overall contribution of these top four predictors explain about 86.4% for RF model and about 82.7% for GBM model of the variance in NO_x. The partial dependence plots for the top four predictors identified by the GBM and RF models are shown in Fig. 5.

The partial dependencies of NO_x from each predictor are consistent between the two models. As evident, NO_x concentrations were strongly affected by wd. The highest concentrations of the NO_x are associated with winds blowing from SW to NW, i.e., in the direction of both several of the COVA plant conveyed emissive sources and the SS598 national road. The traffic contribution to the observed concentrations was supported by the analysis of the daily and weekly NO_x pattern. The former (Fig. 6a) tends to be significantly bimodal (higher concentrations in the early morning and late afternoon coinciding with the commuting hours). The latter (Fig. 6b) shows a clear decrease of NO_x concentrations on Saturday and Sunday when traffic is usually lower. The trend represented the second most relevant variable and clearly confirmed the decrease in NO_x concentrations since the beginning of 2016 due to the reasons above discussed. NO_x concentrations slightly decrease or remain constant when ws is lower than 2.5 ms^{-1}. For higher values of ws, NO_x concentrations grow until ws reaches values of 5/6 ms^{-1}, then they remain almost constant. As explained in [28], increases in NO_x concentrations with ws could be indicative of a buoyant plume from a source such

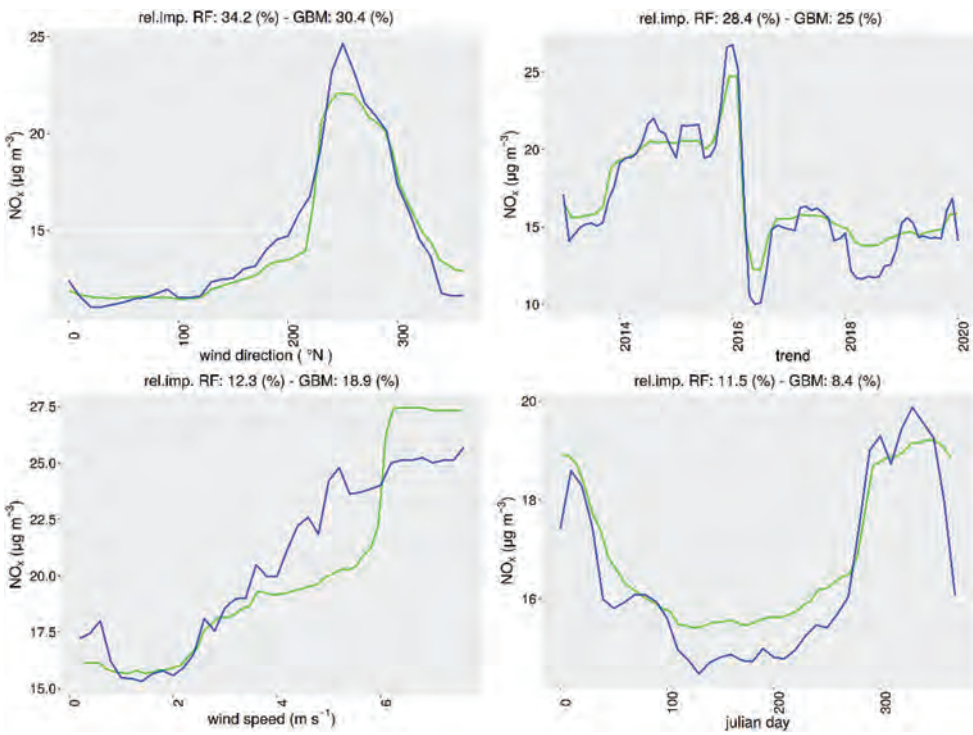

Figure 5: Partial dependence plots showing the variation in hourly NO_x concentrations as a function of the top four explanatory variables used in the GBM (blue line) and RF (green lines) models.

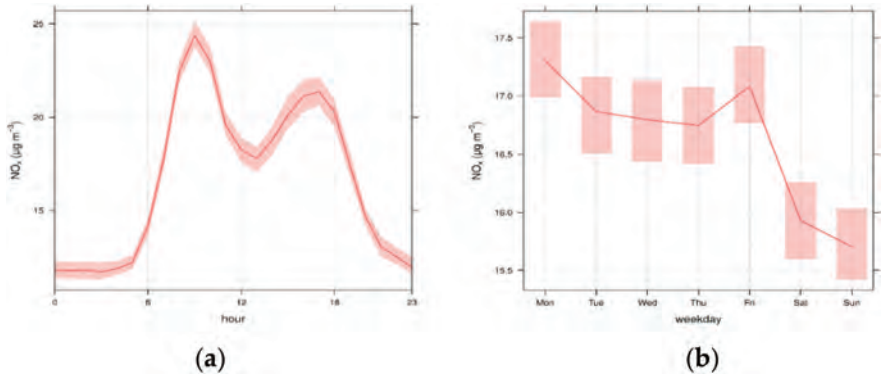

Figure 6: Daily (a) and weekly (b) profiles of hourly NO_x concentrations. Also shown on the plots is the 95 % confidence interval in the mean.

as a chimneystack, where the plume is brought down to ground level when the wind speed increases. This hypothesis is consistent with the presence of conveyed emissive sources in the proximity of the monitoring site. The pattern of NO_x as a function of Jday reflects the seasonal variations in NO_x and shows the expected trend with generally lower concentrations in summer and higher ones in winter: the NO_x concentrations are elevated at lower ambient temperature (T <10°C) and during colder months (Oct–Feb), as these conditions limit the dispersion of emissions and there is a higher demand for domestic heating.

Overall, all the information derived from the analysis of the partial plots confirm the role of the oil plant and the vehicular traffic on the NO_x variability at the study site.

5 CONCLUSIONS

In this work, GBM/RF algorithms were explored as a basis of a meteorological normalization technique. Both models showed high predictive ability in terms of accuracy and minimal errors being able to explain more than 70% of the variance in the NO_x observed concentrations. The ML-based meteorological normalization technique allowed to estimate the real trend of NO_x concentrations and to highlight the role of both the industrial activity and the vehicular traffic on the observed NO_x concentration levels at the monitoring site. Although further refinements may be made in the future, for example, in terms of additional predictors or temporal analysis, the results produced are plausible and coherent with what is expected on the basis of the scientific literature. However, because these methods are all data driven, caution is required when generalizing the results obtained to different conditions and/or sites. Ultimately, the ML-based meteorological normalization techniques are found to represent a robust method to account for the confounding effect of meteorology in air quality time series, thus providing those reliable estimates of pollutant concentration levels and variability that represent a crucial input for the decisions concerning the environmental and public health protection.

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Appendix A

Statistic name	Equation
Mean bias error	$MBE = \frac{1}{N}\sum_{i=1}^{N} M_i - O_i$
Mean absolute error	$MAE = \frac{1}{N}\sum_{i=1}^{N} \lvert M_i - O_i \rvert$
Root mean squared error	$RMSE = \sqrt{\left(\frac{\sum_{i=1}^{N}\left(M_i - O_i\right)^2}{N}\right)}$
Coefficient of determination	$R^2 = \left(\left\{\sum_{i=1}^{N}\left(M_i - \bar{M}\right)\left(O_i - \bar{O}\right)\right\} \Big/ \left\{\sum_{i=1}^{N}\left(M_i - \bar{M}\right)^2\left(O_i - \bar{O}\right)^2\right\}^{\frac{1}{2}}\right)^2$
Index of agreement	$IoA = 1 - \frac{\sum_{i=1}^{N}\lvert M_i - O_i \rvert}{c\sum_{i=1}^{N}\lvert O_i - \bar{O} \rvert}$, when $\sum_{i=1}^{N}\lvert M_i - O_i \rvert \le c\sum_{i=1}^{N}\lvert O_i - \bar{O} \rvert$ $IoA = \frac{c\sum_{i=1}^{N}\lvert O_i - \bar{O} \rvert}{\sum_{i=1}^{N}\lvert M_i - O_i \rvert} - 1$, when $\sum_{i=1}^{N}\lvert M_i - O_i \rvert > c\sum_{i=1}^{N}\lvert O_i - \bar{O} \rvert$ with c = 2

where:
N = total number of hourly measurements; M_i = ith predicted value; O_i = ith observed value;
$\bar{M}$ = mean of the predicted values; $\bar{O}$ = mean of the observed values.

IMPACT OF PIGEON PEA FISH FEED FORMULA ON THE LIMNOLOGY OF SMALL-HOLDER AQUACULTURE SYSTEMS DURING TILAPIA FISH FEEDING TRIALS, VHEMBE DISTRICT, LIMPOPO PROVINCE

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University of Venda, South Africa

ABSTRACT
Inland aquaculture systems are on the rise worldwide, including in South Africa to provide affordable fish and promote local economic growth. But the main cost input, is the supply of fish feed. Thus, there is a need to develop local fish feed to offset the rising cost of commercial fish feed. The study was aimed at assessing the effects of a local low-cost pigeon pea feed on the limnology of aquaculture systems using three types of feed, viz. commercial feed (control), pigeon pea feed (one roasted and one raw). The results as computed by the Czekanowski coefficient statistical analysis showed that the commercial and low-cost feed had similar environmental impacts ($p < 0.05$). When environmental factors fluctuated, there was a fluctuation in phytoplankton composition which led to the proliferation of cyanobacteria species in all the aquaculture tanks. A total of 446 phytoplankton species were identified in the commercial feed tank, 601 species in the roasted fish feed and 630 species in the raw fish feed. Phytoplankton spectra were recorded from six taxonomic groups namely: Chlorophyta, Euglenophyta, Dinophyta, Bacillariophyta, Chryasophyta and Cyanophyta (the dominant taxonomic group). Most of the physio-chemical parameters were within the recommended aquaculture guidelines of the Department of Water & Forestry, making the feed suitable for fish feeding. The results show that the three fish feeds (commercial feed, roasted pigeon pea feed and raw pigeon pea feed) all influenced the health of the aquaculture system with both beneficial and harmful algae growing in the system. This shows that the pigeon pea formula has similar impacts on the aquatic health of aquaculture tanks.
Keywords: Cyanobacteria, Cyanotoxin, phytoplankton, water quality, aquaculture, pigeon pea

1 INTRODUCTION

Tilapia fish (*Oreochromis mossambicus*) is one of the most common fishes that is found on abundance worldwide that is enjoyed by many and serves as a staple food for most African homes. As the world's population increases so has the demand for white meat as it is known to be cheaper and much healthier than red meat [1]. Fish farming has been on the rise for the past decade and as such inland aquaculture systems are rising, that is the same case for the Vhembe district in Limpopo Province as the district has fish farmers, some have ponds at their homes [2–3]. Fish farmers who have ponds depend on commercial feed in order to grow their production however the feed is relatively expensive which has a negative impact on their profit which is a major challenge for small-holder aquaculture practitioners [4].

Pigeon pea is plant protein that has been found to replace soya in formulation of local fish feed [5]. A local fish feed was then formulated blending pigeon pea and maize bran and then fed to juvenile tilapia (*O. mossambicus*) [6]. Since we are aware that available nutrients from fish feed may contribute to algae proliferation [3], we assessed the effects of the pigeon pea fish feed formula on the limnology of small-holder aquaculture systems during tilapia fish feeding trials, Vhembe district, Limpopo Province, South Africa.

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2 MATERIALS AND METHODS

2.1 Location of the study area

The study was done in the north-eastern corner of Limpopo Province, Thohoyandou, in the Vhembe District (Figure 1). The fish tanks were situated on the premises of University of Venda in the School of Agriculture and were populated with *O. mossambicus*. The study area is located at 22°57′30″S and 30°26′15″E.

2.2 Sample collection and onsite physical measurements

A total of 36 water samples were collected and of which 12 water samples were collected from each of the fish tanks. The fish tank 1 (a commercial fish feed), tank 2 (ground pigeon pea formula mixed with maize bran) and tank 3 (roasted, ground pigeon pea mixed with maize bran). The study period was 12 weeks, from November 2016 to January 2017. The water samples were collected once a week (on Fridays) using a 200 ml no-transparent sterile water bottles. The water samples were carried in a cooler box with ice inside. The physical water quality parameters: pH and temperature were measured in-situ using a multimeter instrument (Jenway 430, England) and calibrated as per manufacturer's guideline and the Total dissolved solids (TDS) and electrical conductivity were determined with a multimeter instrument (Wasser Profession, Austria) and calibrated as per manufacturer's guideline Turbidity was measured using a turbidity meter (Oakton T-100, Eutech Instruments, USA) calibrated as per manufacturer's guideline. All measurements were in triplicate.

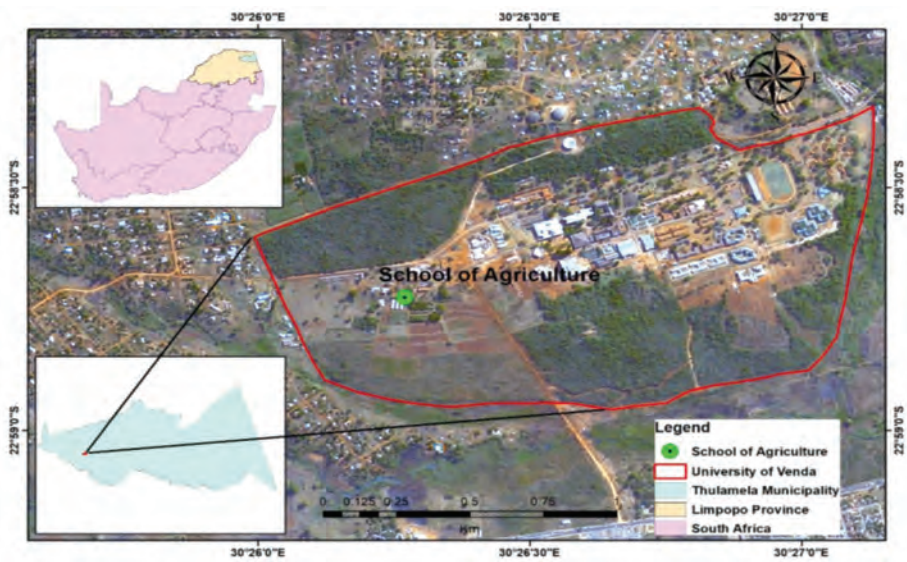

Figure 1: The study site (University of Venda, Vhembe district).

2.3 Laboratory analysis

The Ion Chromatography instrument (Metrohm, Germany) was used to determine chloride, sulphate and nitrate and phosphate in the water samples. The ammonium concentration was determined using the photometer and ammonium test kit according to the procedure of Sehnitzler et al. [7]. The metals, zinc and lead were measured in the laboratory using a flame atomic absorption spectrometer (FAAS) with a double beam and deuterium background corrector.

2.4 Cyanobacteria and phytoplankton collection

Cyanobacteria and phytoplankton samples were collected 12 times, i.e. once a week over a period of 12 weeks (November 2016 to January 2017) using a phytoplankton net with mesh size of 25 µm. The samples were collected on the fifth day of each week (every Friday) because water quality parameters were needed to determine their effects on cyanobacteria. The cyanobacteria and phytoplankton samples were collected at the depth of 5–90 cm, using a hand held phytoplankton net with a 10-cm radius with a mesh size of 25 µm net placed inside the tank and moved in a zig-zag motion (moved from the middle of the tank to the left end of the tank, then moved to the right end of the tank via the middle of the tank, in order to collect specimen that dwell at the tank end and the middle of the tank) as the tanks size was 1.2 m which is big enough for phytoplankton to freely swim around in it, 200 ml dark non-transparent bottles were used to collect the samples. Rocks, leaves and other debris were taken out of the collected sample.

2.5 Cyanobacteria and phytoplankton analysis

Laboratory analysis consisted of two parts which were the analysis of soft algae and analysis of hard algae. For the soft algae analysis, organisms were enumerated in a settling chamber using an inverted microscope with 10x and 40x objectives. A sample of 30 ml was extracted from each of the 100 ml collected samples without using a syringe filter, the samples settled for 24 h before analysis. Another 30 ml was extracted from the 100 ml containers and filtered with a 45-µm filter and the samples settled for 24 h before being analysed using the flow cam. Enumeration on the flow cam was carried out by running 6 ml of the filtered samples through the enumeration chamber, each sample was run 3 times which meant the 18 ml of each sample was enumerated

For hard algae analyses, 30 ml from each of the collected samples were poured into an enumeration chamber and allowed to settle for 24 h and enumerated using a compound Amscope IN480 TC-10M microscope at 1250x magnification. The abundance of the specimen was weighed by manually counting the number of sampled species (per 6 ml analysed). The abundance of both soft and hard algae was done by using an elimination process where identified specimen were recorded as either being present or absent in each sample/tank, the genera/species which were not identified in other tanks were recorded as 0 and the identified ones were recorded using any number >0 (depending on the number of identified species number), the specimen were identified by using a chart adopted from Smithsonian Environmental Research Centre [8]. Cyanobacteria were identified by using a cyanobacterial identification

kit by Janse et al. [9], as done by the North-west University in collaboration with the Department of Water Affairs South Africa.

2.6 Data analysis

The Microsoft (MS) Excel 2013 was used to compute the mean and standard deviation of the replicates, differences between the three fish feeds (commercial feed, raw pigeon pea feed formula and roasted pigeon pea formula) were analysed using one-way ANOVA at level of significance at $p < 0.05$.

Cyanobacteria and phytoplankton presence, absence and abundance were used to determine the diversity of phytoplankton. The Czekanowski coefficient was used to measure the similarities and dissimilarities in abundance of the enumerated species between the three tanks used as different sampling points. Species abundance in Tank 1 was compared to Tank 2. Species abundance in Tank 1 was compared with Tank 3 species abundance. Species abundance in Tank 2 was compared to abundance in Tank 3.

The Czekanowski coefficient (SC) was calculated as follows:

$$\mathrm{SC} = \frac{2\sum \min\left(X_i, Y_i\right)}{\sum X_i + \sum Y_i},$$

where X_i and Y_i are the abundance of species in two tanks and $\Sigma\min(X_i,Y_i)$ = the sum of lesser scores of species where it occurs in both quadrants.

3 RESULTS AND DISCUSSION

3.1 The physical–chemical quality of the water in the fish tanks

The average pH values from Tanks 1, 2 and 3 were alkaline; none of the values were acidic (Figure 2a). There was no significant difference among mean pH values $p > 0.05$. This may indicate that the pigeon pea formula was comparable with the commercial fish feed as fish survival is dependent on the water's pH as fish and most beneficial phytoplankton cannot survive in acidic environments. According to DWAF [10] aquaculture guidelines basic-alkaline waters are most suitable for fish growth. The pH ranges agree with study of Yada and Ito [11] who said that *O. mossambicus* tolerate alkaline conditions for their optimum growth. The alkaline conditions also promote the growth of soft algae such as (*Bacillariophyta*, *Anabaena* and *Chlorophyta*), the production of these soft algae led to clogging in the water filters which were used for water circulation. *Cymatopleura W. Smith* is one of the phytoplankton that strives/prefers alkaline still waters and it was found in abundance in the three tanks as through the sampling period the water was alkaline in the tanks. Chlorophyta is beneficial algae which may be a source of nutrition for *O. mossambicus* [12]. The deep in pH on week 5 was associated with a heat wave that was taking place in South Africa during that time [13].

The total dissolved solids (TDS) and electrical conductivity (EC) in all the fish tanks was below DWAF [10] aquaculture guidelines basic of 1,200 ppm (Figure 2b–c). There was no significant difference among mean TDS and EC values $p > 0.05$. The highest TDS concentration (279.3 mg/L) was recorded in Tank 2 which contained raw feed during the 11th week. This phenomenon showed that the feed contained a lot of dissolved ions hindering/impeding the growth of Bacillariophyta and promoting the growth of *Microcystis*. However, when the

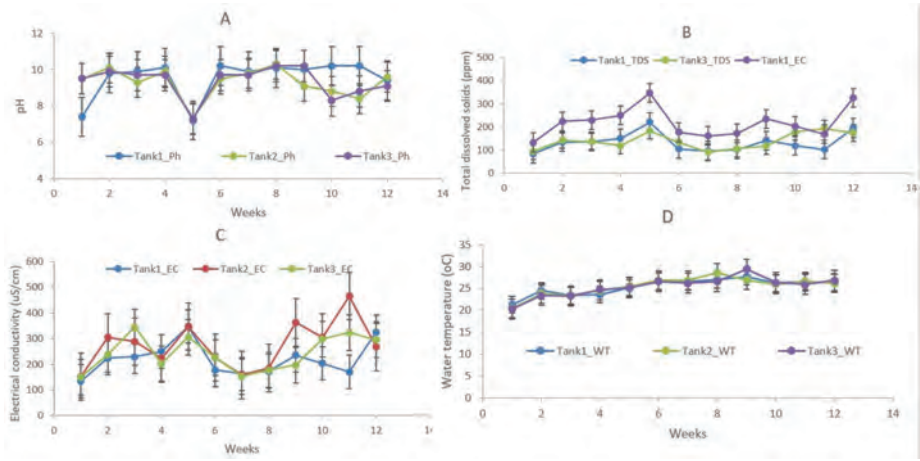

Figure 2: The variation of physical quality of the water: (a) pH, (b) total dissolved solids, (c) electrical conductivity and (d) water temperature in the fish tanks. Whiskers indicate the error bars of the mean.

TDS values went up in week 5 (in all tanks) due to the massive heat wave that was experienced in South Africa [13], algae which are intolerant to alkaline water and high TDS levels such as (Cryptophyta) disappeared in all the tanks this indicated that conditions were getting intolerable for fish survival.

Temperature is an essential factor when it comes to fish and phytoplankton survival. Phytoplankton can tolerate temperatures ranging from 16°C to 27°C and start to disappear at 28°C [14] whereas tilapia fish species can tolerate temperatures ranging from 15°C to 30°C [10]. There was no significant difference among mean water temperature values $p > 0.05$. The water temperature was below 30°C and compiled with the DWAF [10] aquaculture guidelines (Figure 2d). These temperature conditions are ideal for the growth for both fish and phytoplankton. However, during week 9 some algae and phytoplankton started to disappear as the temperatures were getting intolerable for some of the species, species such as *Craticula grunow* and *Sphaerodinium woloszynska* are heat intolerant. However, with the high-temperature readings, growth of *Anabaena*, was associated with death of fish in the tanks (10 fish died in tank 1, 7 fish died in tank 2, 13 fish died in tank 3) during week 5.

The nutrients, ammonium, nitrates and soluble phosphates, were available in the fish tanks in variable concentrations. The level of nitrate in the tanks were within the desired nitrate range of 0.1–4.5 ppm and the DWAF target value is 300 ppm [11], except for one extreme value of 5.3 in tank 2, week 9 (Figure 3a). This was due to a technical error (failed water pump) so the water was not circulated to the biofilters to remove excess nitrates. There was no significant difference among mean nitrate values $p > 0.05$. The availability of nitrates is due to bacteria nitrification of ammonia [10] and the fish feed itself [3]. The fish excrete ammonia as a waste, and this is converted to nitrates. The presence of nitrates is not harmful to fish [10]. However, the excess nitrates stimulate the growth of algae, as shown by bad odour and watercolour changing to dark green in the fish tank, showing growth of algae (*Chlorophyta*, *Cyanophyta*, *Euglenophyta*, *Dinophyta* and *Bacillariophyta*) causing decrease in dissolved oxygen, during the first weeks there was rapid growth of phytoplankton.

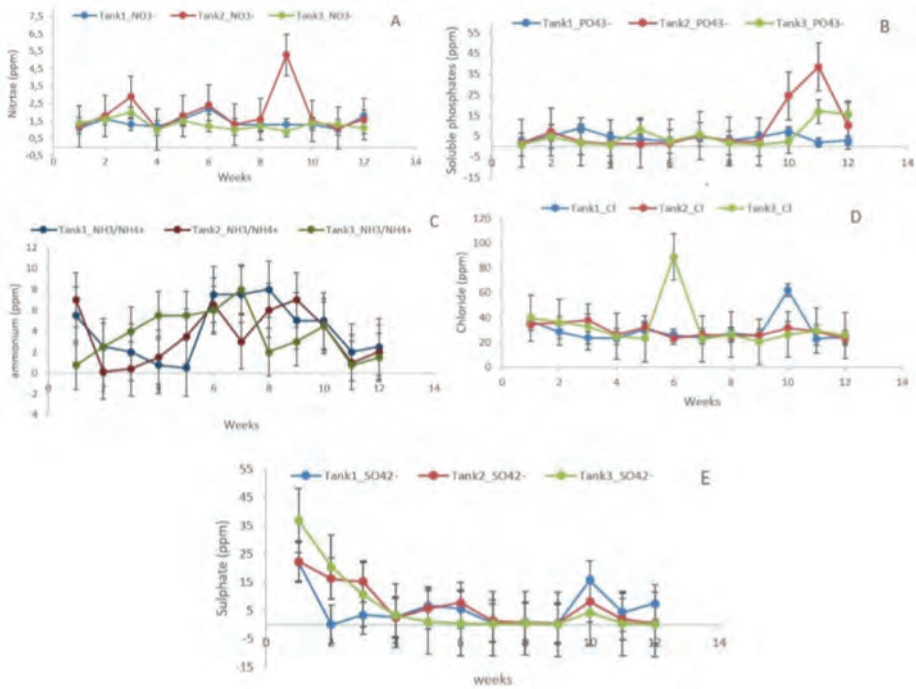

Figure 3: The variation of chemical quality of the water: (a) nitrate, (b) soluble phosphates, (c) ammonia/ammonium, (d) chloride and (e) sulphate in the fish tanks. Whiskers indicate the error bars of the mean.

The 0.6 ppm phosphates are the maximum desired level set by DWAF [10]. The phosphates levels in this study were variable, mean range was from 0.01 to 3 ppm, some recorded values were above the desired level (Figure 3b). There was no significant difference among mean phosphates values $p > 0.05$. In Tanks 2 and 3, probably due to weak circulation of the water pumps, there were high levels of phosphates that were recorded on week 11. The water pumps were clogged by *Closterium Nitzsch ex Ralfs*. The pump was used to circulate the water through the biofilters which were designed to remove excess phosphates. The source of phosphates is fish feed and animal excreta. The presence of phosphates is not harmful to fish. But the excess phosphates stimulate the growth of phytoplankton and algae (species such as *Anabaena*, *Cocconels Ehrenberg*, *Peridinium Erhrenberg*, *Euglena Ehrenberg* and *Dityosphaerium Nageli*).

Ammonium is an important substance in every ecosystem as it is needed to balance the nutrient cycle in the aquatic system, ammonium is unavoidable in aquatic systems especially fish aquariums/tanks and ponds as fish feeds are introduced into the systems frequently; ammonium can be converted to nitrates or ammonia provided that there is enough oxygen (O) for the conversion to occur [15]. All the three tanks had levels of ammonium levels (Figure 3c) which were within the fish survival rate (<8 ppm) [10]. There was no significant difference among mean ammonium values $p > 0.05$. The highest recording was captured in Tank 2 in week 9 (0.5 ppm), this was due to scums forming in the tanks which prevented light penetration, in turn, there was not enough oxygen in the tank to convert the ammonium

to nitrates. In all the tanks where there was a decrease in ammonium, reading there was an increase in nitrates reading, in all the three tanks during week 10, there was a decrease in ammonium reading as there was water that was added and the water contained a lot of oxygen. The ammonium values did not show any sign of extremity as there was no external anthropogenic or natural pollutants which had high ammonia content being introduced into the system. Furthermore, since every aquatic ecosystem has nitrosamines bacteria which can convert ammonium, there was a lot of conversion on the little ammonium that was available to nitrates. The levels of ammonium did not favour the growth of phytoplankton such as *Cryptomonas Ehrenberg* which cannot withstand high ammonium levels, the levels were also suitable for tilapia farming as they had no direct negative effect on the health of the fish.

The chloride levels were variable in the fish tanks but within the DWAF [10] of 600 ppm (Figure 3d). There was no significant difference among mean chloride values $p > 0.05$. High levels of chloride in this study did not affect the health of *O. mossambicus.* As stated by Barnabe [16], most species cannot withstand high chloride levels as chloride is known to destroy the membranes and cells of most microspecies. However, it was observed that *Microcystis*, *Dinophyta* and *Euglenophyta* species disappeared in tank 1 during week 10 and tank 3 during week 6.

The sulphate levels were variable in the fish tanks (Figure 3e). There is no DWAF guideline value [10], since sulphate is considered as non-toxic in comparison with hydrogen sulphide. There was no significant difference among mean sulphate values $p > 0.05$. Conversely, sulphate does not easily affect the health of fish as it can change during oxidization. The sulphate values in all the tanks were below 35 ppm and this influenced the normal growth of phytoplankton (i.e. all of the recorded 6 phyla: *Cyanophyta*, *Chrysophyta*, *Bacillariophyta*, *Dinophyta*, *Euglenophyta* and *Chlorophyta*).

The metals, zinc, lead, cadmium and mercury levels were variable in the fish tanks (Figure 4). According to Britz and Hecht [17], zinc (Zn) is an essential element responsible for fish growth and metabolism in the required concentrations. The zinc levels were variable in the fish tanks but within the DWAF [10] salmonids guideline value of 0.5 ppm (Figure 4a). There was no significant difference among mean zinc values $p > 0.05$. There was a slight increase in Zn in tank 3 during week 7 (where there was a heat wave). The zinc levels in the three tanks did not have a negative effect on the survival of fish as the levels were within the recommended levels. However, the zinc levels did have a negative impact on the growth of *Pinnularia Ehrenberg* which is a beneficial alga to fish as they can feed on it when food is scares. The other recorded species (Table 1) under the six phyla remained in high abundance as Zn did not influence them.

The lead levels were variable in the fish tanks but within the DWAF [10] guideline value of 10 ppb (Figure 4b). There was no significant difference among mean lead values $p > 0.05$. Lead is not an essential element, is a pollutant and does not contribute to fish physiology. The lead values were low and did not have a negative effect on fish survival in the three tanks. The growth of most phytoplankton that was recorded cannot be affected by Lead (Pb) thus lead has no known effect on the abundance of phytoplankton species as stated in Carignan [18].

The cadmium levels were variable in the fish tanks but within the DWAF [10] guideline value of 0.2 ppm (Figure 4b). There was no significant difference among mean cadmium values $p > 0.05$. Cadmium is not an essential element and does not contribute to fish physiology. The cadmium values were low and did not have a negative effect on fish survival in the three tanks. Most of the cadmium values were below the detection point <0 ppb and as such cadmium did not have a detrimental effect on the limnology. Even though cadmium was

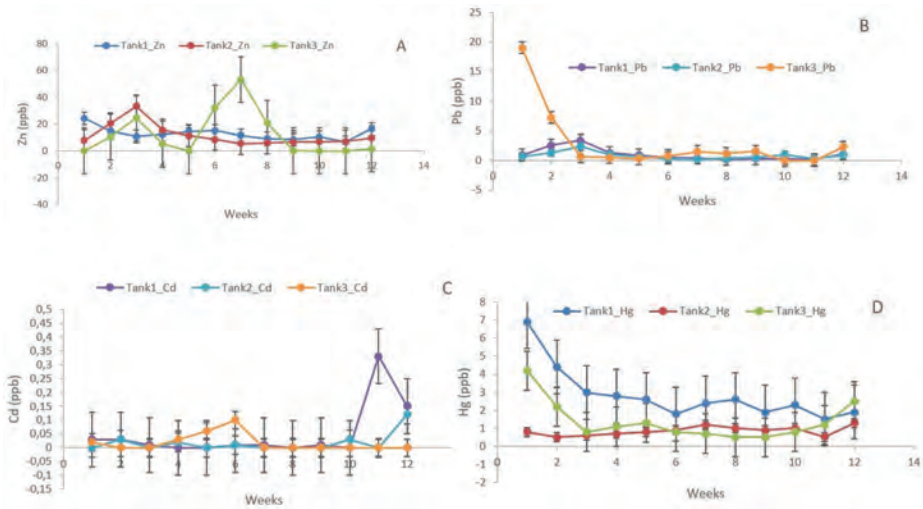

Figure 4: The variation of metals in the water: (a) zinc, (b) lead, (c) cadmium, and (d) mercury in the fish tanks. Whiskers indicate the error bars of the mean.

present, it was in very low levels and in such levels, it did not have any effect on the phytoplankton abundance and the fish health. The same results were found by Edwards et al. [19], when assessing the health of the delta stream using the fish index in polluted streams, it was noted that, cadmium did not have effects on the aquatic life of the delta.

The mercury levels were variable in the fish tanks but within the DWAF [10] guideline value of 1 ppm (Figure 4d). There was no significant difference among mean mercury values $p > 0.05$. Mercury is not an essential element and does not contribute to fish physiology. Mercury is a metal which is usually not found in high values in normal environmental circumstances, for mercury values to be found in high toxic values, there must be a lot of organic and inorganic pollution occurrence [20]. The levels of mercury did not also favour the growth of most phytoplankton as mercury destroys most phytoplankton cells, but since the levels were low, mercury could not completely destroy the phytoplankton that were growing there as the other physio-chemical parameters were favouring the growth of the phytoplankton as such the six phyla that were recorded were striving throughout the experiment as mercury did not destroy them.

3.2 Phytoplankton biodiversity in the three tanks over the sampling period

The presence of physio-chemical parameters influenced the growth of algae/phytoplankton as shown in Table 1. The identified genera were quantified, with (0) meaning that the genera were not present in that tank and any number above zero (>0) meaning that the genera were identified in that particular tank.

The three tanks had high phytoplankton/algae abundance recorded with tank 2 having the highest number of species being recorded (630) under 22 genera and 5 phyla, followed by tank 3 with (601) species under 22 genera and 5 phyla and lastly tank 1 with the least species recorded (446) under 21 genera and 5 phyla.

Table 1: Phyla/genera (absence, presence, and abundance), for all sample weeks.

Phyla/genera	**Fish tanks**			**Total per genera/spp.**
	1	2	3	
1. ***Cyanophyta***				
i. Anabaena	**42**	**48**	**57**	**147**
ii. Cylindrospermopsis	**17**	**34**	**28**	**79**
iii. Microcystis	**85**	**102**	**71**	**258**
iv. Oscillatoria	**27**	**18**	**30**	**75**
2. ***Chrysophyta***				
i. Dinobryon Ehrenberg	**20**	**14**	**11**	**45**
ii. Mallomonasperty	**7**	**5**	**9**	**21**
iii. Cryptomonas Ehrenbeg	**6**	**13**	**18**	**37**
3. ***Bacillariophyta***				
i. Asterionella Hassall	**0**	**3**	**8**	**11**
ii. Aulacoseira Thwaites	**5**	**27**	**17**	**49**
iii. Cocconels Ehrenberg	**14**	**35**	**12**	**61**
iv. Craticula Grunow	**12**	**7**	**15**	**34**
v. Cymatopleura W. Smith	**16**	**32**	**21**	**69**
4. ***Dinophyta***				
i. Peridinium Erhrenberg	**20**	**25**	**37**	**82**
ii. Sphaerodinium Woloszynska	**5**	**17**	**22**	**44**
5 ***Euglenophyta***				
i. Euglena Ehrenberg	**62**	**73**	**51**	**186**
6. ***Chlorophyta***				
i. Ankyra fott	**12**	**17**	**9**	**38**
ii. Chlamydomonas Ehrenberg	**34**	**57**	**79**	**170**
iii. Closterium Nitzsch exralfs	**14**	**9**	**22**	**45**
iv. Crucigeniella Lemmermann	**7**	**13**	**10**	**30**
v. Dityosphaerium Nageli	**25**	**44**	**32**	**101**
vi. Golenkinia Chodat	**4**	**22**	**18**	**44**
vii. Stigeoclonium Kutzing	**12**	**15**	**24**	**51**
Total	**446**	**630**	**601**	**1,677**

The high number of species in tank 2 shows that there was nutrient overload from the feed used in tank 2 (raw feed), the high nutritional value of the feed led to high nitrates values being recorded in tank 2 with the average of 1.9 ppm, the feed was not bounded therefore it broke apart and settled easily. The high nutrient content of the feed also led to over nitrifications in the tank. According to Bruisma [21], when there is nutrients' overload, the abundance

of zooplankton decreases in aquatic systems, which is in contradiction with the results from this study where there is high abundance when there is nutrient overload. However, a study by Kugrens [22], conducted in North America concluded that there was an increase in algae/phytoplankton when there is an increase in pollution, however, not all phytoplankton can tolerate high nutrient levels which explains the nonexistence of *Asterionella Hassall* in tank 1 (Table 1).

All the six (6) identified phyla were present in all the tanks (Tanks 1, 2 and 3). Phylum cyanophyta was the most identified phylum in Tank 2 with 202 species/genera being identified, under this phylum genera such as *Microscystis*, *Cylindrospermopsis*, *Anabaena* and *Oscillatoria*, were identified. These identified genera are known to produce cyanotoxins such as *microcystin*, *cylindrospermopsin*, *anatoxin-a*, and *microcystin-LR* respectively. *Microcystis* was the most abundant genera under phylum Cyanophyta. Under the phylum *Cyanophyta*, *Microcystis* were identified in high abundance in all the three tanks, the *Microcystis* are not easy to get rid of, as such the fish were the source of the *Microcystis*, the Mokgopong farm water (where the fish were bought) tested positive for *Microcystis* presence, swabs from the fish's mouth and gills also showed the presence of *Microcystis* which explains the high abundance of the *Microcystis*. Phylum Chlorophyta was the most identified phylum in tank 3 with 194 species from seven genera, *Dinobryon* Ehrenberg was the most abundant species under phylum Chrysophyta. Similarly, Chlorophyta was the most abundant phylum in tank 2 with the species *Chlamydomonas Ehrenberg* being the most abundant one.

The Dinophyta phylum was most abundant in tank 3 with *Peridium Ehrenberg* being the most abundant species identified (Table 1). Phylum Euglenophyta was in abundance in tank 2 as the production of phosphate was high in that tank, *Euglena Ehrenberg* species was the only species identified under this phylum with the most species identified in tank 2. The Chlorophyta phylum was the phylum with the greatest number of species/genera identified, under Chlorophyta, *Chlamydomonas Ehrenberg* was the most identified species. Out of all the identified phyla, it was only the *Asterionella Hassall* species which was not identified in tank 1 during the entire sampling period, the rest of the species were identified in all the three tanks.

Phytoplankton/algae have different nutritional requirements with some species requiring a high amount of nutrients and some requiring minimum nutrient levels [23]. There were a lot of fluctuations in the physio-chemical parameters because of different reasons hence the fluctuations in those parameters together with the continual introduction of pollutants (fish feeds) caused nutrient overload in the systems. Starting from the first week of sampling there were phytoplankton identified in the system, nutrient overload intolerant phylum such as Bacillariophyta were recorded during the first weeks of sampling and disappeared when the system got polluted/stressed. However, since groundwater was being used to dilute the over nitrified systems the phylum Bacillariophyta did not completely disappear however, during week 3 and week 12 when the three systems were stressed, the abundance of that phylum was low/minimal as the phylum is not tolerant to pollution, the phylum Bacillariophyta was found in all the three tanks as the phylum requires turbid and slow moving water and such conditions were recorded in all the tanks. The abundance of this phylum seem to be high when compared to the others phylum, e.g. Chrsophyta because there was a lot of water dilution (which brought down the levels of physio-chemical parameters favouring Bacillariophyta) during the sampling period and there were also times where the systems were flushed completely when cleaning the clogged filters, e.g. during week 9. *Euglenophyta* is intolerant to high nutrient content and as such the phylum is not found in abundance and was absent in in tank 2 where the phosphate average was 8.2 ppm.

Unlike Dinoflagellates, Diatoms cannot move on their own, however, they depend on water currents for distribution [14] the distribution of the diatoms in the system was a result of the bio-filters used for water circulation which shows why the species were distributed almost equally in the system. The bio monitoring results and Czekanowski calculation results showed that there was high similarity between the three tested feed. The similarity between the commercial fed and the roasted feed was at 78%, it was 66% between the commercial feed and the raw feed, it was at 81% between the raw feed and roasted feed.

4 CONCLUSION

The physio-chemical parameters (pH, total dissolved solids, temperature, turbidity, chloride, nitrate, phosphate, sulphate, ammonium, zinc, lead, mercury and cadmium) were assessed and were found to be within the prescribed aquaculture guideline limits. This may show that the local fish feed is not harmful to tilapia fish (*O. mossambicus*) and is comparable to the commercial fish feed. The pigeon pea fish feed formula like any animal feed influenced the assemblage of cyanobacteria and phytoplankton as such there were micro-species that grew in the freshwater system. However, the assemblage of cyanobacteria and phytoplankton was not extreme as compared to the commercial fish feed. There were phytoplankton phyla such as Cyanophyta and Bacillariophyta that are known to produce cyanotoxins when all the conditions are favourable, however, the conditions in this study were not stable enough for cyanotoxins production.

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SUSTAINABLE WATER RESOURCES MANAGEMENT 2021

OVERVIEW

With the main objective to preserve our delegates' wellbeing, but also with the belief that the scientific community should not be stopped, WIT decided that Sustainable Water Resources Management 2021 should not take place as scheduled, in Milan, Italy, but take place as an online event instead.

The conference was organised by the Wessex Institute, UK and the Polytechnic University of Milan, Italy, represented by Professor Stefano Mambretti.

The conference, which started in Halkidiki, Greece in 2001, is well-established and always attracts a wide international spread of delegates. The variety of topics covered by the conference reflects the complex interaction of water resources management while considering economic constraints and the effects on the community.

OPENING OF THE CONFERENCE

The conference was opened by Professor Stefano Mambretti who welcomed the delegates to the event.

INVITED PRESENTATIONS

There were a series of invited lectures on advanced topics of research and applications, as follows:

"Graph theory and community detection for elementary DMA design", **Professor S. Mambretti**, Polytechnic University of Milan, Italy.

"Long-term perceptions and actions of the public to address sustainable water resources management in the Pacific Northwest, USA", **Professor R. Mahler**, University of Idaho, USA.

"The virtual water flow of crops in the semiarid Ceará, Brazil: The impacts on the state's water resources management", **Dr M. Zelenakova**, Technical University of Kosice, Slovakia.

"Updated rainfall series and their trends for mainland Portugal (1913-2019)", **Professor M Portela**, Tecnico Lisboa – Lisbon University, Portugal.

"Probabilistic estimation of runoff from green roofs", **Professor G. Becciu**, Polytechnic University of Milan, Italy.

"Valuation of a community company and its impact on development strategies" and "Communication methods on water care during the COVID-19 pandemic and its impact on the resilience of the rural community of 'Libertador Bolivar', Ecuador" **Professor P. Carrion Mero**, ESPOL Polytechnic University, Ecuador.

CONFERENCE SESSIONS

The papers presented during the conference were focused on the following topics:

- Water Management
- Ecological and Environmental Impact
- Water and the Community
- Hydraulic modelling
- Erosion and sediment transport
- Flood risk management

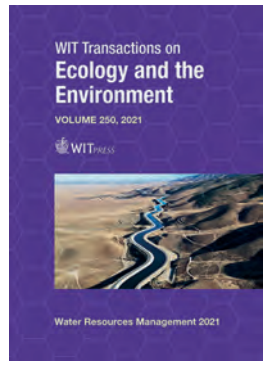
Q&A LIVE ZOOM SESSIONS

Conference delegates were invited to participate in two Q&A Live Zoom Sessions which took place on Tuesday 18th and Wednesday 19th May 2021. These friendly sessions were a great opportunity for participants to interact with each other and ask questions to authors about their papers.

CONFERENCE PUBLICATION

Accepted papers presented at this conference are published in Vol. 250 of the WIT Transactions on Ecology and the Environment (ISSN 1743-3541). Papers included in this volume are available Open Access in the eLibrary of the Wessex Institute (https://www.witpress.com/elibrary) from where they can be freely downloaded by any interested parties.

A few papers were selected for publication in this Journal.



CLOSING OF THE CONFERENCE

We are very sorry that we were not able to meet our delegates in person this year.

We would like to thank the delegates for participating in the event and look forward to meeting them at the next conference in the series.

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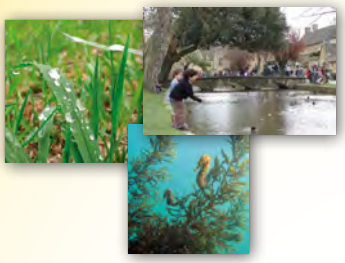

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