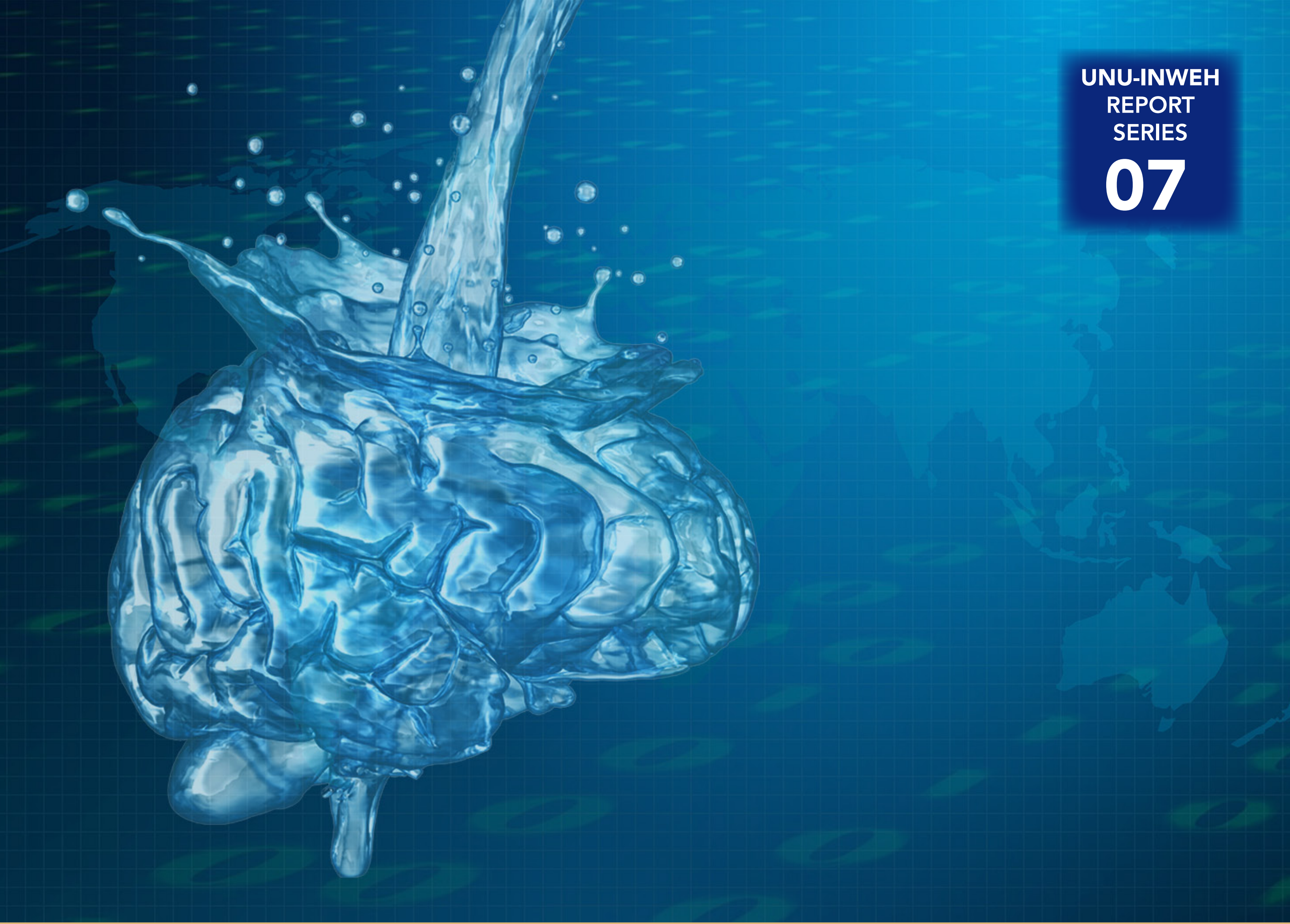

Higher Education in the Water Sector: A Global Overview

Colin Mayfield

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CONTENTS

EXECUTIVE SUMMARY

Higher education related to water is a critical component of capacity development necessary to support countries' progress towards Sustainable Development Goals (SDGs) overall, and towards the SDG6 water and sanitation goal in particular. Although the precise number is unknown, there are at least 28,000 higher education institutions in the world. The actual number is likely higher and constantly changing.

Water education programmes are very diverse and complex and can include components of engineering, biology, chemistry, physics, hydrology, hydrogeology, ecology, geography, earth sciences, public health, sociology, law, and political sciences, to mention a few areas. In addition, various levels of qualifications are offered, ranging from certificate, diploma, baccalaureate, to the master's and doctorate (or equivalent) levels.

The percentage of universities offering programmes in 'water' ranges from 40% in the USA and Europe to 1% in sub-Saharan Africa. There are no specific data sets available for the extent or quality of teaching 'water' in universities. Consequently, insights on this have to be drawn or inferred from data sources on overall *research* and teaching excellence such as Scopus, the Shanghai Academic Ranking of World Universities, the Times Higher Education, the Ranking Web of Universities, the Our World in Data website and the UN Statistics Division data. Using a combination of measures of research excellence in water resources and related topics, and overall rankings of *university teaching excellence*, universities with representation in both categories were identified. Very few universities are represented in both categories. Countries that have at least three universities in the list of the top 50 include USA, Australia, China, UK, Netherlands and Canada.

There are universities that have excellent reputations for both teaching excellence and for excellent and diverse research activities in water-related topics. They are mainly in the USA, Europe, Australia and China. Other universities scored well on research in water resources but did not in teaching excellence. The approach proposed in this report has potential to guide the development of comprehensive programmes in water. No specific comparative data on the quality of teaching in water-related topics has been identified.

This report further shows the variety of pathways which most water education programmes are associated with or built in – through science, technology and engineering post-secondary and professional education systems. The multitude of possible institutions and pathways to acquire a qualification in water means that a better 'roadmap' is needed to chart the programmes. A global database with details on programme curricula, qualifications offered, duration, prerequisites, cost, transfer opportunities and other programme parameters would be ideal for this purpose, showing country-level, regional and global search capabilities.

Cooperation between institutions in preparing or presenting water programmes is currently rather limited. Regional consortia of institutions may facilitate cooperation. A similar process could be used for technical and vocational education and training, although a more local approach would be better since conditions, regulations and technologies vary between relatively small areas.

Finally, this report examines various factors affecting the future availability of water professionals. This includes the availability of suitable education and training programmes, choices that students make to pursue different areas of study, employment prospects, increasing gender equity, costs of education, and students' and graduates' mobility, especially between developing and developed countries.

This report aims to inform and open a conversation with educators and administrators in higher education especially those engaged in water education or preparing to enter that field. It will also benefit students intending to enter the water resources field, professionals seeking an overview of educational activities for continuing education on water and government officials and politicians responsible for educational activities.

Keywords: *Sustainable Development Goals, SDG 6, water education, water studies, university rankings*

INTRODUCTION

The roles of education in achieving the SDG6 targets are broad and can be classified into three areas: i) provision of highly qualified personnel with Baccalaureate, Masters and PhD (or equivalent) degrees; ii) provision of technical and management personnel and iii) provision of community education and community leaders. This report focuses primarily on the first group – university-level education. It attempts to develop approaches to rank the quality of water-related higher education throughout the world, or, at the very least, stimulate further thinking in this direction.

Water-related education is a vast and diverse topic, and there are no global data sets specifically focusing on measures of water education. The study extracted information from related data sources and published data on water studies and research, combined these with data on teaching, and drew inferences from both. These data were only available for universities and not for most colleges or other forms of professional education. The overriding goal was to assess the types and quality of educational activities relevant to the water sector, to summarise the current situation and assess the possible future pathways to maintain and upgrade the educational processes.

RANKING WATER PROGRAMMES AT UNIVERSITIES

Data and methods used for ranking

There is no global data source with any degree of detail on educational activities in the water sector. Studies and data on the various aspects of water education, such as undergraduate and graduate degree programmes, or technical and professional education and training activities are fragmented and often not available. Even the number of universities in the world is not known with certainty. The website Ranking Web of Universities (2019) lists more than 28,000 universities based on their web presence. However, this number is certainly low as they list only 3270 US universities of the more than 4350 degree-granting institutions listed in the National Center for Education Statistics (2019).

Data were obtained from Scopus (2019), the Shanghai Academic Ranking System (2019), the Times Higher Education (THE) website (Times Higher Education, 2019a), the Ranking Web of Universities (2019), Our World in Data (2019) and the UNESCO Institute for Statistics (UNESCO-UIS, 2019a), and The Ranking Web of Universities (Ranking Web of Universities, 2019) databases. The THE has a database assessing the *quality of teaching* at their 1250 listed universities in 2019, but most other databases have data only on *research, funding and publishing activities*.

The overall numbers of degrees offered in water-related programmes in different countries were extracted from the Shanghai database, but this database lists only 1200 universities, which represents a small sample.

The quality of Water Resources research in universities has been assessed (together with 54 other academic subjects) by the Shanghai Academic Ranking System (Shanghai Academic Ranking System, 2019) using several indicators, including:

1. PUB - the number of papers authored by an institution in an Academic Subject during the period of 2012-2016. Only papers of 'Article' type are considered.
2. CNCI, Category Normalised Citation Impact (CNCI) - the ratio of citation of papers published by an institution in an academic subject during the period of 2012-2016 to the average citations of papers in the same category, of the same year and same type. A CNCI value of 1 represents world-average.
3. IC, International collaboration (IC) - the number of publications that have been found with at least two different countries in addresses of the authors divided by the total number of publications in an academic subject for an institution during the period of 2012-2016.
4. TOP - the number of papers published in top journals in an academic subject for an institution during the period of 2012-2016. Top journals are identified through Shanghai Ranking's Academic Excellence Survey or by Journal Impact Factor.
5. AWARD - the total number of staff who won a significant award in an Academic Subject since 1981.

For each indicator, the value for an institution is calculated as a percentage of the top scored institution. The square root of the percentage is multiplied by the allocated weight for that indicator and then the scores for each indicator are added and the final scores ranked in descending order. The total score for Water Resources for each university listed is calculated from these indicators in the proportion of 100, 100, 20 100 and 20, for the respective indicators 1 to 5. Using these scores, the top 50 of the 200 universities rated that offered Water Resources studies are listed in *Table 1* together with data on their rank and scores in teaching excellence for 2019 from the THE. This THE teaching ranking was derived from a consideration of student/faculty ratios, funding, and teaching reputation. As another set of comparisons, those top 50 universities in Water Resources overall rankings in the Shanghai Academic Ranking System (2018) ranking and the THE (2019) overall ranking were also extracted.

Table 1: Number of excellent research-intensive universities in countries with at least 1 university ranked in the top 100 from the Ranking Web of Universities (Ranking Web of Universities, 2018)

Country	Top 100	Top 202	Top 500	Top 1000	Top 5001	Top 10006	All
USA	58	91	159	258	1041	2278	3257
UK	7	17	42	80	142	193	280
Australia	6	8	22	34	42	69	188
Canada	5	13	24	34	81	158	355
China	4	11	39	105	490	1403	2208
Germany	3	13	38	60	134	270	465
Netherlands	3	6	11	13	34	59	133
Switzerland	3	5	7	11	24	49	102
Denmark	2	3	5	6	9	19	76
Belgium	2	2	6	8	17	35	82
Hong Kong	1	4	6	6	13	15	21
Japan	1	3	13	26	268	459	980
Norway	1	2	4	4	23	34	50
Singapore	1	2	2	3	11	22	45
Brazil	1	1	7	20	177	299	1394
Taiwan	1	1	6	20	91	132	160
Finland	1	1	5	10	19	35	46

Water Resources is a sub-category of Engineering in the Shanghai Academic Ranking system and is therefore restrictive in its scope. To overcome this restriction, a method was devised for this Report to assess research expertise in the universities in the other fields related to water studies in the Shanghai Academic Ranking System. Measures of research excellence in fields or topics closely related to water studies (Geography, Ecology, Earth Sciences, Civil Engineering, Environmental Science and Engineering, Remote Sensing, Biology, Agricultural Sciences, Public Health, Sociology, Public Administration, Law, and Political Sciences) when combined with the THE assessment of teaching excellence, revealed a list of universities that excel in multiple categories related to water. This perspective was necessary as water-related teaching programmes do not necessarily correlate with the research activities in water. But the presence of highly-rated research programmes in these other subject areas – all relevant to an integrated programme of teaching in water – indicate that that university has the essential expertise to deliver well-rounded and complete teaching effort on water-related topics.

A survey of university programmes in water chosen first from the top 50 universities active in Water Resources research, then with web and database searches to find more examples, was done to find common points and differences in programme and course curriculum design. Few of the top 50 universities in Water Resources published sufficiently detailed curricula, but 55 examples were eventually identified with an appropriate level of detail.

Results of University Ranking

Prominent research-intensive universities are concentrated in North America (particularly in the United States), Europe and parts of Asia. *Table 1* list countries that contain at least one university rated in the top 100 for research activities (Ranking Web of Universities, 2018). The total number of universities examined was 28077 and the numbers in each of the categories (top 100, top 202, top 500, top 1000, top 5001, top 10006, and all) for those countries are also given. This is arguably a more complete measure of quality than simply listing the top 100. The criteria used to rank universities is described in detail at the Webometrics website (Ranking Web of Universities, 2019).

North America and Europe have the highest percentage of countries with universities offering programmes in water, and Sub-Saharan Africa has the lowest (*Table 2*). Note that only universities ranked in the Shanghai System (Shanghai Academic Ranking System, 2019) were considered.

The programmes offered attempt to educate baccalaureate-level and post-graduate students in water issues, but there is considerable variation in the scope, content and rigour of these programmes.

Table 2: Regional distribution of universities offering a programme in water (only those ranked in the Shanghai Academic Ranking system are included).

SDG Region	Percentage (%) of Universities Offering a Programme in Water
Northern America and Europe	40
Western Asia and Northern Africa	16
Eastern Asia and South-eastern Asia	16
Latin America and the Caribbean	16
Central Asia and Southern Asia	7
Australia and New Zealand	3
Sub-Saharan Africa	1

In some baccalaureate-level education programmes (especially in the professional schools such as engineering, medical and legal) it is possible and desirable to set up standardised curriculum systems that cover those topics deemed to be essential for becoming qualified in that field. The water education environment has nothing like this, except for some engineering and geotechnical/geology schools. Whether this type of qualification is desirable for the water sector is not obvious – it has many complex interacting fields of study and expertise and a more general, professional-style, qualification may not be relevant or needed for most practitioners.

The universities ranked in the top 50 for Water Resources by the Shanghai Academic Ranking System do not always score high in overall quality as measured by either the Shanghai or THE rating systems (*Table 3*). This diversity in overall rankings versus excellence in water resources indicates that there are different paths to excellence. This can be a result of a general level of excellence at a university or an effort to excel in this particular area of expertise.

The top 50 university rankings for Water Resources do not account for the fact that universities that have a water-related programme or programmes can implement them at the graduate level rather than, or in addition to, the undergraduate level; either as a course-based or a research-based master's or Ph.D. degree. This is a recent development that takes students already qualified in some water-related field and gives them a general overview of the entire water sector. This approach is typically not designed to produce people qualified in multiple areas. Rather, it attempts to improve their collaboration skills, establish a common vocabulary and understanding of other sectors so that communication between practitioners in the water sector is improved.

Table 4 shows the results of extracting from a list of the top 50 universities in Water Resources those that also were listed in the top 50 in 13 topic areas, in the Shanghai database, that are of relevance to water: Geography, Ecology, Earth Sciences, Civil Engineering, Environmental Science and Engineering, Remote Sensing, Biology, Agricultural Sciences, Public Health, Sociology, Public Administration, Law, and Political Sciences. This is relevant, as excellence in a narrowly-defined Water Resources category – a subset of *engineering* research – does not necessarily translate to a university having broad expertise in all the related areas that are important in modern water management education and practise.

The top 50 universities worldwide in each of those areas were found according to the criteria of the Shanghai Academic Rankings for 2017 – the latest year with very complete data. Each topic area had different importance for the indicators used – such as prizes and medals earned, conferences, and publication in top journals. Each of the criteria were chosen by Shanghai to best represent the particular topic area. Each topic had a final score that was calculated according to a slightly different accumulation of indicators, where the percentage of each individual indicator making up the total was different. This was an attempt to best reflect the individual characteristics of that particular topic area.

The universities in *Table 3* with excellence in many water-relevant topics have, at the least, the potential to establish a well-rounded set of courses or programmes on water issues. This does not imply that other universities cannot deliver excellent programmes, only that these top universities are recognised as having excellent and productive research activities in both engineering Water Resources research and recognised excellence in many different areas of relevance to water; and that opens an opportunity to provide excellent teaching programmes.

Universities that ranked in the top 50 both for excellence in teaching from the THE and in excellence in Water Resources in the Shanghai Ranking (Table 3) were Duke, Stanford, Tsinghua, the Texas at Austin, Cornell, Princeton, the MIT and the Illinois at Urbana-Champaign.

Universities that ranked in the top 50 both in teaching excellence from the THE (Table 3) and in at least 2 of the 13 water-related topic areas (Table 4) are Duke, the

Table 3: Top 50 Water Resources universities with countries and scores based on the Shanghai Academic Ranking (2018), compared with their teaching excellence scores on the Times Higher Education (2019) and their overall ranking in the Shanghai 2018 and Times Higher Education 2019 ranking systems.

Rank	Universities ranked as the top 50 for excellence in Water Resources in the Shanghai Academic Ranking	Country	Total Score: Water Resources	Teaching Score from Times Higher Education Supplement 2019	Overall Rank in Shanghai Academic Ranking, 2018	Overall Rank in Times Higher Education Supplement 2019
1	University of Arizona	USA	297.7	43.4	101-150	159
2	Swiss Federal Institute of Technology Zurich (ETH)	Switzerland	284.8	83.3	19	11
3	Delft University of Technology	Netherlands	270.7	58.1	151-200	58
4	University of California, Berkeley	USA	265.6	78.7	5	15
5	The University of New South Wales	Australia	265.2	45	101-150	96
6	Texas A&M University	USA	264.3	51.6	151-200	171
7	Beijing Normal University	China	260.6	nr	201-300	nr
8	University of California, Davis	USA	258.9	59.3	96	59
9	University of Bristol	UK	258.3	44.8	74	78
10	Hohai University	China	258	nr	nr	nr
11	University of Illinois; Urbana-Champaign	USA	254.5	63.2	41	60
12	Flinders University	Australia	250.9	25.7	401-500	251-300
13	Tsinghua University	China	248.9	87.7	45	22
14	University of Colorado at Boulder	USA	247.6	45	38	114
15	University of California, Irvine	USA	244.4	44.5	83	96
16	The University of Texas at Austin	USA	241	68.8	40	39
17	University of Wageningen	Netherlands	239.7	49.2	101-150	59
18	University of Saskatchewan	Canada	237	35.7	301-400	401-500
19	Swiss Federal Institute of Technology Lausanne	Switzerland	235	66.5	81	35
20	The University of Queensland	Australia	234.9	47.3	55	69
21	Wuhan University	China	233.3	48	201-300	301-350
22	Colorado School of Mines	USA	226.5	32.9	nr	251-300
23	Stanford University	USA	223.3	93.6	2	3
24	Oregon State University	USA	223.2	31.3	151-200	301-350
25	University of Padua	Italy	222.5	39.9	201-300	201-250
26	Utrecht University	Netherlands	222.3	43.8	51	74
27	Cornell University	USA	222.2	79.7	12	19
28	The University of Adelaide	Australia	218.1	32.8	101-150	135
29	Colorado State University	USA	218	29	201-300	401-500
30	Imperial College London	UK	217.9	85.8	24	9
31	Vienna University of Technology	Austria	217.3	40.2	301-400	251-300
32	University of Waterloo	Canada	215.1	32.2	151-200	201-250
33	National Taiwan University	Taiwan	214.8	54.9	151-200	170
34	University of Aberdeen	UK	213.8	30.5	201-300	158
35	Princeton University	USA	213.4	89.9	6	7
36	The University of Melbourne	Australia	213.2	68	38	32
37	Université Grenoble Alpes	France	212.3	32.4	151-200	301-350
38	Ghent University	Belgium	211.9	44.9	61	143
39	Duke University	USA	211.7	84.1	26	18
40	Polytechnic Institute of Milan	Italy	211.6	33.2	201-300	301-350
41	Northwest A&F University	China	211	19	nr	801-1000
42	University of California, Santa Barbara	USA	210.8	50.9	46	52
43	Lancaster University	UK	210.3	36.5	301-400	146
44	University of Oslo	Norway	210	39.8	62	121
45	Monash University	Australia	209.2	46.1	91	84
46	University of Nebraska - Lincoln	USA	209.1	32.2	151-200	351-400
47	Uppsala University	Sweden	209.1	44.3	63	87
48	Massachusetts Institute of Technology	USA	209	91.9	4	4
49	University of British Columbia	Canada	208.8	60.8	43	37
50	Pennsylvania State University - University Park	USA	207.7	53.2	74	81

Note: "nr" - not rated

Table 4: Universities (from the top 50 in "Water Resources" by Shanghai Academic Ranking (Shanghai Academic Ranking System, 2017)) with 2 or more of the 13 water-relevant research areas (see text) where those universities are also listed in the top 50 for that particular topic.

University	Number of water-relevant research areas where the university is ranked in the top 50 for those areas
University of California, Berkeley	13
Stanford University	9
Swiss Federal Institute of Technology Zurich	8
University of British Columbia	8
Utrecht University	8
Duke University	7
Pennsylvania State University - University Park	6
The University of New South Wales	6
The University of Queensland	6
University of Colorado at Boulder	6
University of Illinois at Urbana-Champaign	6
University of Wageningen	6
The University of Texas at Austin	5
University of California, Davis	5
Beijing Normal University	4
Colorado State University	4
Ghent University	4
National University of Singapore	4
Texas A&M University	4
Tsinghua University	4
University of Bristol	4
Delft University of Technology	3
KU Leuven	3
Monash University	3
Nanjing University	3
Paul Sabatier University (Toulouse)	3
Swiss Federal Institute of Technology Lausanne	3
Tongji University	3
University of Arizona	3
University of California, Irvine	3
University of Lisbon	3
University of Oslo	3
Vienna University of Technology	3
Wuhan University	3
Islamic Azad University	2
Nanyang Technological University	2
Northwest A&F University	2
Polytechnic University of Catalonia	2
Technical University of Denmark	2
University of Saskatchewan	2
University of Waterloo	2

Note: Some universities in the top 50 in Water Resources did not have representation in the top 50 of any of the other topic areas

National University of Singapore, Stanford, California (Berkeley), and Illinois at Urbana-Champaign.

This analysis does not recognise or acknowledge the universities or university institutes, faculties or departments that specifically offer some form of integrated water programmes. Even though they do not necessarily appear in 'Top 50' topic area listings their programmes may still be excellent, and they may provide opportunities for learning in depth about the many aspects of water.

The curricula of the 55 universities used to compare programmes in water showed significant correlation, albeit under different titles and categories of courses. The most common topics, in decreasing order of occurrence were hydrology, chemistry and physics of water, watersheds, water quality, pollution, microbiology of water, water management (including IWRM), ecology (including ecosystem management and valuation), public health, river and stream morphology and flow, toxicology, groundwater, political and sociological aspects of water, risk (assessment, management and

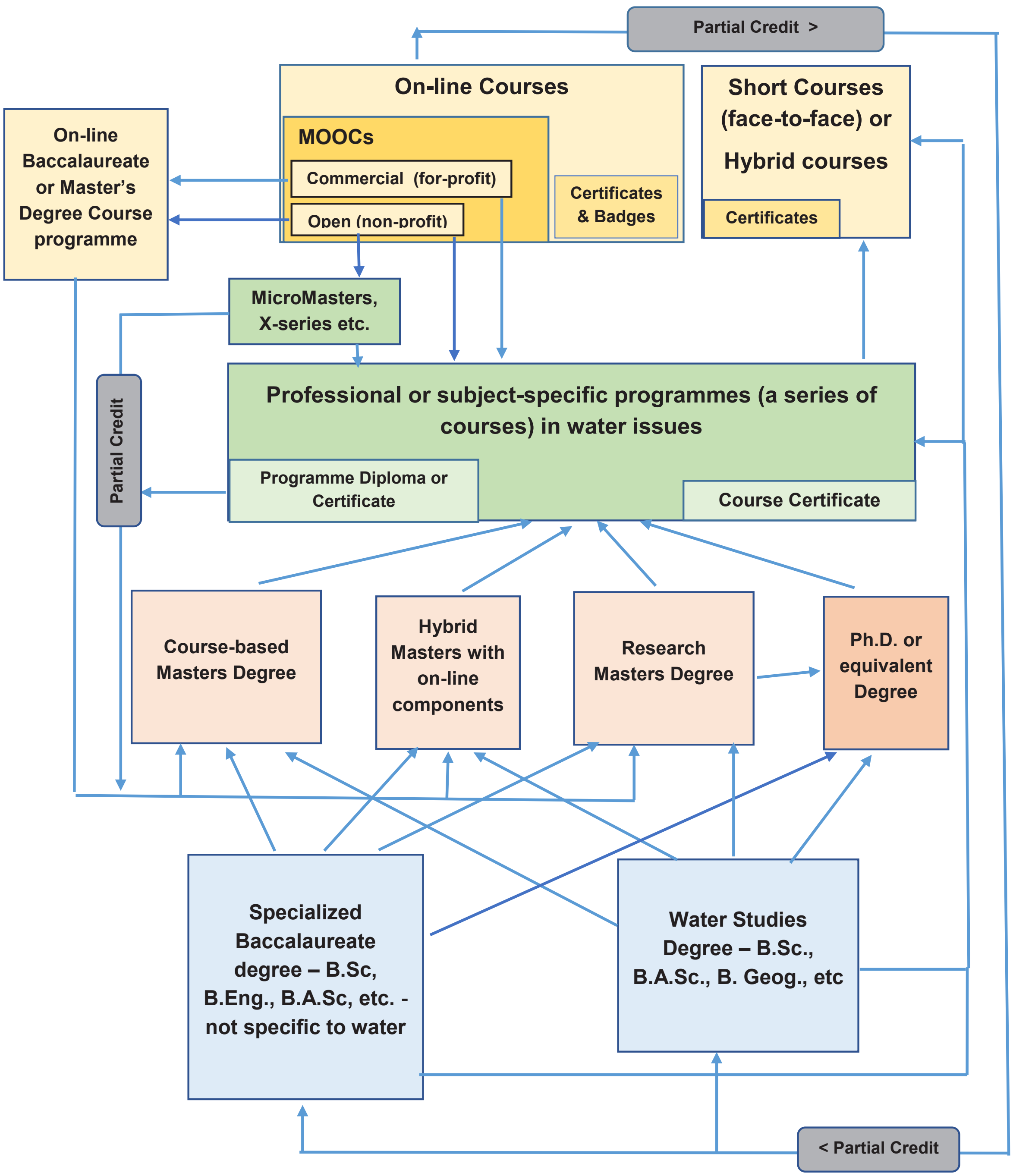

Figure 1: Diagram of typical progress through the science, technology and engineering education system at the graduate level

communication), water law and transboundary issues. This, by necessity is a somewhat limited view of the water curriculum at universities since it is based on only those that had detailed curricula available, but it does show the wide range in topics in a water curriculum. Many other topics were covered depending upon the focus of particular programmes, but the listed topics were the most common.

STUDENT PROGRESS THROUGH POST-SECONDARY EDUCATION

Figure 1 shows the typical pathways through the science, technology and engineering post-secondary and professional education system and most, but not all, water programmes are in that group. There are many local and regional variations. In some countries there are additional or equivalent qualifications and designations. For example, equivalent to a Ph.D. are the designations Doctor of Science (DSc) in the USA, Japan, South Korea, and Egypt, Doctor of Juridical Science and Doctor of the Science of Law in the USA., Dr. rer. nat. or Doctor rerum naturalium ("Doctor of the things of nature") in Germany, Doktor Nauk (Doctor of Science) in Poland and Russia and Doctorate by dissertation in Japan.

There are two main types of master's degrees: course-based (taught) and research-based. Course-based master's degrees are usually based on modules delivered in lectures, seminars, laboratory work or distance learning, while research-based master's degrees require the student to carry out their own research project in a specialised field of study, often of a longer duration than course-based master's degrees. Some master's programmes are now hybrid in nature, taught partly through on-line courses or by changing the mix of course and research activity so that the courses comprise a larger proportion of the program.

It is clear that there are many possible "routes" to obtaining a qualification in the water sector, ranging from an on-line certificate to a Ph.D. or equivalent qualification. The possible pathways through the system are complex but flexible, allowing for multiple ways to obtain a given qualification. The role and importance of on-going education after the initial qualification is obtained is not specifically detailed in *Figure 1*, but will become more significant as policy, technology and research and development innovations continue in the future. The role of individual short courses and various short course programmes in the water sector is significant. The courses range from 1-day, on-site, courses given to relatively small groups to longer course programmes (typically 3 to 5 days). These would typically not grant specific qualifications but would be offered locally by institutions such as the universities, private sector agencies, UN agencies, or NGOs.

The educational system at the university level is obviously complex with many different routes and qualifications available to students who wish to work in the water sector. It is a particularly challenging choice for students as the range of possible courses of relevance to a career in water is extremely large. Some degree of specialisation is almost inevitable, but efforts have been made, and should continue, to expose students to important concepts in water in addition to those in their chosen speciality.

UNIVERSITIES AND EMPLOYMENT IN THE WATER SECTOR

Employment opportunities for water professionals

An increasing trend is for governments to encourage universities to produce graduates that can be employed based on some kind of analysis of future of employment prospects or industry requirements. Whether this should be the function of a university can be debated, but an analysis of employment opportunities and trends is useful for decision makers whether they be potential students or academic personnel. These analyses may, in part, determine the subject areas that are chosen by students.

Many factors influence the number of graduating students in particular fields of study and those numbers cannot always be predicted accurately. Enrollment trends vary both short-term (year by year) and longer term. The factors that will determine the numbers of students graduating in water programmes include the initial choice of a study program, the cost of programmes, changes in gender equity in programmes, enrollments in overseas universities and student mobility.

Emerald Publishing (Emerald Publishing, 2009)) estimated the size of the water sector market at some $696 billion reaching US $1 trillion by 2020. Their definition of the water sector was the total cost of operational and capital expenditures for water and wastewater operations. Part of this market was the water treatment technology market that was valued at US$1.4 billion in 2015 and is expected to exhibit steady growth to US$1.9 billion by 2022. The global water treatment industry will show significant growth in the coming years, owing to the rise in awareness about water scarcity, innovations in water treatment technologies, and investments by companies and government in R&D in this sector.

New technologies will emerge and be incorporated into water and wastewater treatment systems; some will be large, industrial-scale systems such as nanoscale catalyst systems and improved membrane technology, and some will be 'point of entry' and 'point of use' small-scale or household systems. The skills and abilities required of water professionals will reflect these changes. The skills required in the future will almost certainly differ from those required today. The water sector is not alone in this, most professions and technical/managerial personnel will need new or enhanced skills in the future. Using trends analysis, workshops of experts and machine learning methods, key trends such as automation, environmental sustainability, urbanisation, inequality, political uncertainty, technological change, globalisation and demographics were extracted by (VanderArk, 2017) to arrive at a description of what the overall work environment will look like in 2030. Some 10% of the workforce are in occupations that are likely to grow; 20% are in occupations likely to shrink; and 70% are in occupations that cannot be predicted accurately today, but where redesign of occupations coupled with retraining may promote growth within that group.

Extrapolating from these predictions, in the water sector the occupations likely to show the most growth will be in education and training, the public sector, the design, digital and engineering fields and the service components of the water sector. In the job market, the skills that will be in demand are not only technical knowledge, but increasing interpersonal skills such as teaching, social perceptiveness and coordination and related skills in psychology and anthropology.

The most important skills, knowledge and abilities identified in many studies were Learning Strategies, Psychology, Instructing, Social Perceptiveness, Sociology and Anthropology, Education and Training, Coordination, Originality, Fluency of Ideas and Active Learning (The Guardian, 2019).

These skills are not typically taught or emphasised in water sector education and training and this new perspective should be considered and incorporated in educational activities. Future skills that will be in demand can best be summarised as 'interpersonal' – with the ability to interact, coordinate, teach and learn. Some 120 skills, abilities and knowledge components are described in the comprehensive set of variables (Bakhshi, Downing, Osborne, & Schneider, 2017).

The rate of increase in research spending in the top 1000 companies (GlobeNewsWire, 2017) has declined progressively over the past years but today is gradually increasing. Following this trend, the water sector will still need research personnel, but the rapid increases in the need for research professionals and skills of the past may not continue.

Water Environment Federation Task Force on Workforce Sustainability (final report not available but referenced at the Environmental Protection Agency website as (US-EPA, 2019) projects that in the next decade years, 37% of the water utility workers and 31% of wastewater utility workers in the USA will retire. As a result, the EPA, states and industry organisations are working to promote the water sector and ensure that there is a pool of qualified water professionals to meet current and future needs. At the global scale, while detailed numbers are not available, it is probable that a similar situation exists, exacerbated by the need to install, manage and operate new facilities to serve the population increases expected in many countries.

The global projection for water jobs' growth is positive. The population increases and upcoming retirement of many water professionals in developed countries is creating a number of pressing problems in water management, infrastructure, water security, and new water technologies. This will generate new employment prospects in both developed and developing countries.

Factors influencing availability of trained personnel

Many factors affect the availability of water professionals and technical/managerial staff in the future. They include the availability of suitable education and training programmes, the *choices that students make* to enter different areas of study, employment prospects, increasing gender equity, costs of education and student mobility, especially between developing and developed countries (e.g. emigration of skilled personnel after graduation and the return (or not) of students educated in other countries).

The *choices that students make* about their field of study has evolved over the years (Figure 2); more students enter a programme in business fields (business, administration and law – 25%) than any other field and the social sciences, humanities, education, services, health and welfare and business, administration and law now make up more than 70% of the total. The more technical fields such as natural sciences, mathematics and statistics, engineering, manufacturing and construction, agriculture, forestry, fisheries and veterinary and information and communication technologies make up only 25% of the total (UNESCO-UIS, 2019a).

This study shows large differences between choices made in different countries, for example, choice of education as a field of study ranged from 31% in Mozambique to 1.2% in Bangladesh.

There are no mechanisms to extract water-related programmes from this distribution, but elements are present in the natural sciences, mathematics and

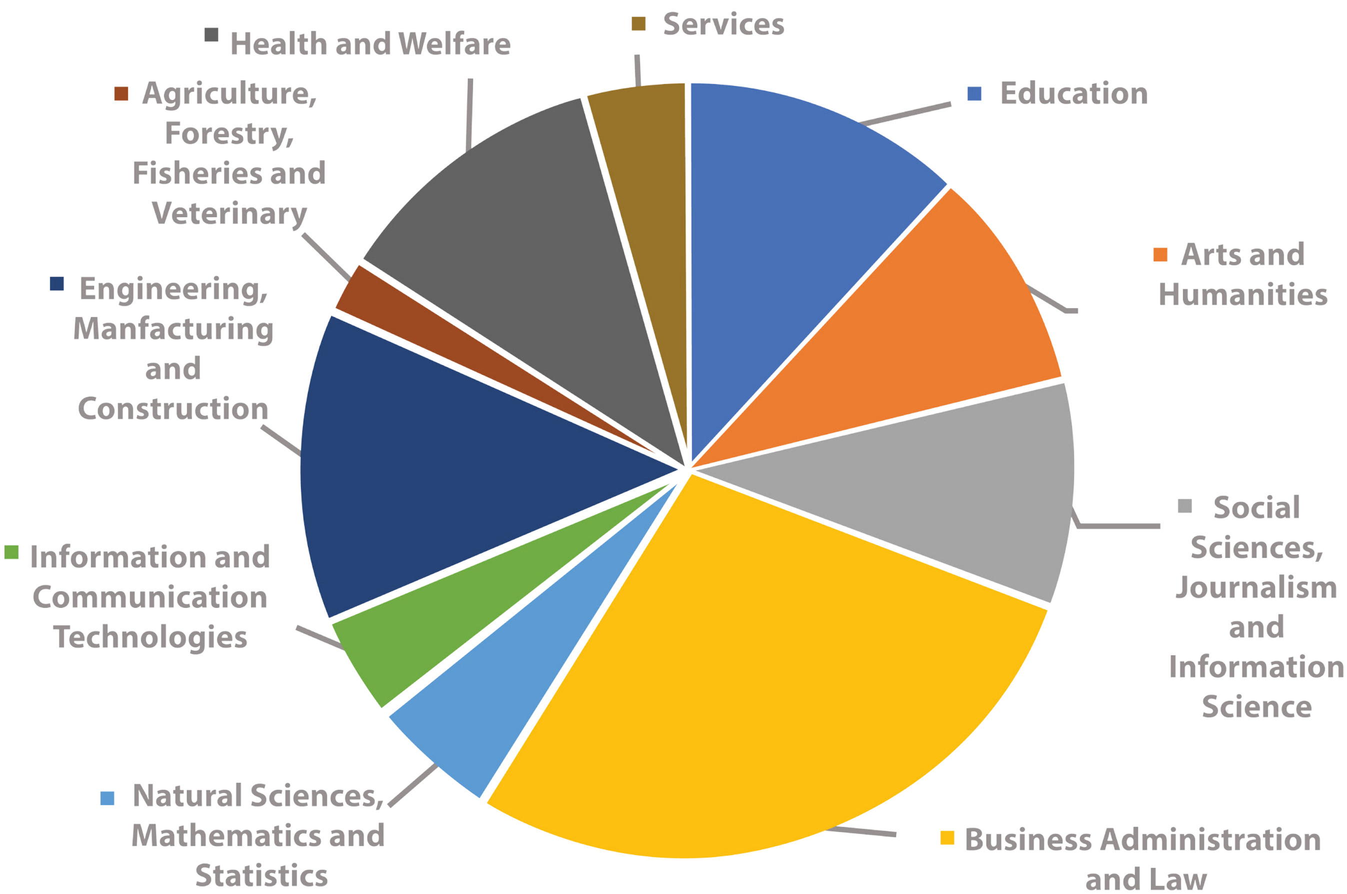

Figure 2: Chosen fields of study for university students (average of % for all countries listed for 2016 in the UNESCO-UIS database (UNESCO-UIS, 2019a).

statistics, health and welfare, engineering, manufacturing and construction grouping. Many essential types of expertise for water-related studies and projects are within the orbit of the scientific technological, engineering and mathematics (STEM) areas. Along with, and competing with, the many other enterprises that rely on development of these kinds of expertise, a sustained decrease in enrollments in these fields would cause severe problems for the water sector.

Gender equity has improved considerably from previous levels in most countries. More women than men complete tertiary education in 80% of countries with available data. Women outnumber men at the level of the Baccalaureate level (53% to 47%). This also true at the master's level (55% to 45%) but reversed at the Ph.D. level (men are 54% of graduates and 71% of all researchers). Women are more likely to graduate from four fields of tertiary education: Education (66% in 88 out of 113 countries with available data in 2016); Humanity and Arts; Social Sciences, Business and Law; and Health and Welfare. Men are the majority of tertiary graduates in three fields: Information and Communication Technologies; Engineering, Manufacturing and Construction; and Agriculture. Among these programmes, a significant gender imbalance can be seen in Engineering, Manufacturing and Construction with 60% men in 92 out of 103 countries with available data in 2016 (UNESCO, 2018).

Only about 29% of the world's researchers are women, but they outnumber men in Argentina, Armenia, Azerbaijan, Bolivia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Myanmar, New Zealand, Panama, Thailand, Trinidad and Tobago, Tunisia and Venezuela (UNESCO, 2018).

This is both a problem and an opportunity. The problem is how to get more women into STEM fields and research positions. The opportunity is to enlarge and improve the number and quality of STEM researchers by including more women.

The *cost of education* varies considerably around the world. Some countries – Denmark, Brazil, Germany, Finland, Greece, Ireland, Mexico, Norway and Poland – have free tuition. Most others have tuition costs ranging from almost zero – France, Columbia and Switzerland – to very substantial – US$10,000 in the US and the UK. In the high tuition countries student debt

Table 5: Total number of foreign students studying in the 10 most popular destination countries in 2017 (UNESCO, 2019b)

Rank	Destination country	Total number of foreign students
1	United States	971,417
2	United Kingdom	432,001
3	Australia	335,512
4	France	245,349
5	Germany	244,575
6	Russia	243,752
7	Canada	189,478
8	Japan	143,457
9	China	137,527
10	Malaysia	124,133
	Total	**3,067,201**

Table 6. Region of origin for outbound international students studying in North America and Europe – 2015. (HolonIQ, 2019)

Originating Region	Number of students
Arab States	468,762
Central and Eastern Europe	450,692
Central Asia	271,434
East Asia and the Pacific	1,367,025
Latin America and the Caribbean	312,128
North America and Western Europe	692,933
South and West Asia	568,830
Sub-Saharan Africa	367,482
Small Island Developing States	101,241
World	5,085,159

has become a serious problem. The student loan debt in the United States is over $1.4 trillion; 620 billion more than credit card debt (HolonIQ, 2018).

Students in other countries (*Table 5 and Table 6)* can be a significant source of trained personnel for their countries of origin if they return. As the top ten host countries are developed countries, many do not and stay home or move to developed countries – a net loss of expertise to the country of origin and a gain for the new country of residence. An undetermined number of these internationally mobile students could have played a role in the water sector in their country of origin. Any incentive, process or practice that encourages the return of these highly-qualified students to jobs in the water sector could benefit the home country. In one example, in 2000, one of every three African migrants (32%) was educated at a tertiary level.

It is clear from the data in *Table 5* is that there is considerable student mobility. Many students come to North America and Europe to study from every other world region (*Table 6*). This is despite the fact that student fees for foreign students in many developed countries are significantly greater than those for citizens of those countries.

Looking at the issue of migration of highly-skilled workers, the effect is different depending on whether absolute (numbers of migrants) or relative (relative proportion of the home country's skilled work force) is considered. For OECD countries, the top eight sending countries in 2000 were South Africa (173,411), Morocco (155,994), Egypt (151,451), Nigeria (148,780), Algeria (87,777), Kenya (80,287), and Ghana (67,105). But considered as a national percentage of the total skilled workforce, small countries have a massive brain drain. For example, Cape Verde (82%), Seychelles (77%), Gambia (68%), and Mauritius (56%) have the highest levels. The numbers cannot be considered as totally reliable as they are based on old data. Collection of this data depends on datasets that do not specifically track the rates of emigration from countries but rely on various calculated numbers and percentages. But they do indicate that the brain drain to OECD countries, at least from Africa, is a serious problem

(Capuano & Abdeslam, 2013). No information on the migration patterns of water professionals is available.

A more detailed analysis of the global flows of students and projected changes up to 2030 reveals a complex web of student movement across the globe (HolonIQ, 2018).

UNIVERSITY COOPERATION AND CURRICULUM IMPROVEMENT

Currently, there are many diverse teaching methods for water topics, and many types of presentation and integration of material. Few examples of cooperation between institutions were found. As a result, there are no common source material repositories or cooperation in producing course curricula in place in any significant or organised fashion.

There is no agreed curriculum design for water resource studies. This is not surprising, given the nature of the subject matter, of universities and their curriculum design process. But, examination of course materials at a number of universities where those materials are published, showed that there are many commonalities in both curriculum design and content. The level of duplication of these materials is significant. The hydrological cycle diagram is present almost everywhere but is produced separately or taken from copyright-free public sources. Given the highly autonomous nature of universities and their faculty members, it would be unreasonable to expect widespread cooperation in curriculum design and delivery, but some sharing of materials would be very beneficial and a mechanism similar to educational content-sharing sites such as Merlot (Merlot, 2019) could be developed.

A consortium of universities heavily engaged in teaching in the water sector would be one mechanism to improve curriculum development both in terms of quality and efficiency. Many examples could be given, but one example might suffice: if all the effort spent in developing new versions of diagrams of the hydrologic cycle were coordinated, a completely interactive, data-driven version incorporating climate and hydrological models could be developed. This would allow exemplar, interactive models of the cycle to be provided to students. As a learning tool, this approach would be vastly superior to the current practice of creating 'yet another cycle diagram'. The diversity of water studies is so great that innumerable similar examples could be found.

This approach would fit especially well with on-line courses. A consortium of universities could offer large-scale water studies, courses or programmes using the specific expertise of their combined faculty members. Many business models and methodologies are now available to accomplish this, and some universities and institutes are beginning on-line water studies programmes (Mayfield, 2017).

Another model that could be transferred from developed to developing countries is the establishment of regional centres of excellence. Popular in developed countries, as physical centres or networked groups of institutions, the concept is applicable to developing countries or regions and could serve as focal points for capacity building in these regions. These regional centres of excellence in water studies should be developed so that local knowledge and expertise is engaged and reflected in the programmes. Some networks of this type are already being established and could be expanded.

EDUCATION DATA: AVAILABILITY AND QUALITY

It must be noted that the lack of data, and the variable quality of any data that are available, is a serious hindrance in assessing the quality and even the extent of water sector educational activities. This is in contrast to the large quantity of data on overall research activities in universities. Even there, water sector research data is not easily available except for specific topic areas such as Water Resources in Engineering - a small part of the overall picture of water studies.

This lack of data on quantity and quality on teaching activities is not surprising. It is considerably more difficult and controversial to assess teaching excellence than it is to develop measures of research output and quality. Commonly-accepted metrics do not exist and those that are proposed are not uniform, measurable on a consistent basis and generally applicable across a range of different countries, programmes, student intakes and teaching and learning philosophies.

Adding to this problem is the diversity of water programmes and qualifications in the water sector. There can be no one measure of what constitutes a programme in water studies as institutions and individual faculty members have widely varying opinions.

Rather than attempt to develop consistent, and probably ineffective and controversial, measures of the quality of teaching activities in the water sector, a better approach might be to look at the outcomes of these activities. Assessments by previous students after different intervals since graduation about the quality, content and relevance of their programmes to their experience in their employment could be one way to assess programmes – perhaps on a regional basis to make the results more relevant to prospective students.

CONCLUSIONS AND RECOMMENDATIONS

There is a lack of data on educational activities in the water sector. Globally organised or annotated information on courses and programmes and on teaching effectiveness and outcomes is not available.

Overall, the state of education and training in the water sector varies considerably between regions of the world, where the developed world has many foci of excellence in water studies that are less common in parts of Africa and Asia. There are also problems of accessibility due to the cost of education in many countries, especially for foreign students, as well as the issue of migration of trained personnel from less-developed countries to more developed ones.

There are universities, mainly in the USA, Europe, Australia and China, that have excellent reputations for both teaching excellence and for excellent and diverse research activities in water-related topics. Other universities scored well on research in water resources but not in teaching excellence. Studies have the potential to develop comprehensive programmes in water, drawing from that expertise. No specific comparative data on the quality of teaching in water-related topics was discovered.

Navigation through the various options available for students to gain an education in water-related areas can be complex. Many different programme options, undergraduate and graduate qualifications, professional and technical programmes and courses, on-campus and on-line courses and transfer possibilities between these programmes exist. Searching for water-related programmes and courses is an onerous task at the moment. The information is spread across many institutional web sites, databases and publications.

From projections of increased deployment of water and wastewater treatment systems around the world, requirements for more technical and professional staff to operate these and current facilities, loss of personnel through retirement, and changes in technology and management systems, employment prospects are good for water-related fields. The rate of increase in research spending has decreased so that employment of research personnel will not increase at levels seen in the past.

A number of factors will determine the enrollment in and graduation from academic programmes that supply the needed personnel. These are the costs and availability of educational opportunities – including the migration of students to developed countries for education and their subsequent rate of return to their home country. Any change in the choices that students make in areas of study, such as decreasing enrollments in STEM subjects and increasing enrollments in business-related programmes and changes due to improvements in gender equity will affect the availability of graduates qualified in STEM subjects. A move away from STEM subjects in general will decrease the availability of graduates in those fields for the water sector, while a shift in gender equity in those subject areas towards greater female participation might counterbalance this effect to some extent.

There are very few examples of cooperation between universities in curriculum design in educational activities in the water sector at the program, course or module level.

For the purposes of improving the practice of water education at universities and making navigation through the multitude of programmes and courses easier for potential students, it may be recommended that a comprehensive survey and data acquisition process needs to be established to summarise and disseminate information on water-related educational activities. In contrast to the diffused nature of this information, large amounts of assimilated data are available on the quantity and quality of research in universities. Measures of overall teaching quality in institutions have been devised but are not designed to address different topic areas of teaching within institutions.

Prospective students should have access to data on the programmes available at the local, regional and global scales. At the very least, a full description of key educational elements should be available in an easily searchable, including: the program; qualifications granted upon successful completion; programme and course curricula; required or recommended pre-requisite knowledge; costs for both citizens and foreign students; course duration; teaching methodologies or philosophies; and examination and assignment requirements.

Curriculum development and updating would be made more efficient by cooperation and sharing of course materials and modules. Consideration should be given to incorporating the 'interpersonal, communication and social skills' that employers are requesting. In the technology area, almost all (98%) of recruiting professionals rate these skills as 'important' for candidates hoping to enter the technology field.

A repository of teaching material could be created, curated and maintained specifically for education in water issues. A consortium of institutions – possibly a

Water-X in an analogy to the university on-line teaching consortium ed-X – could be established to create, assemble and distribute materials for the repository and could produce teaching modules and materials for on-line and on-campus courses.

They could be established on a regional basis to make them more relevant to local requirements. One current attempt is through the Center for Strategic and International Studies where their programme on 'Universities and International Water, Sanitation, and Hygiene' (Center for Strategic and International Studies, 2010) calls for a consortium that 'would allow' universities and colleges engaged in WASH activities abroad not only to work together in a more coordinated fashion, but also to encourage additional technological innovation, strengthen academic, philanthropic and governmental support, and increase momentum for the global WASH sector generally. A consortium would also facilitate a clearing house of information and best practices, which could easily be shared with counterparts outside of academia". A larger scale effort, perhaps starting with some of the top 50 universities in water resources (*Table 3*) and adding those in *Table 4* with significant expertise in the other topics relevant to water studies could be a starting point.

A similar process could be used for technical and vocational education and training (TVET) in the water sector so the training could be made more effective, efficient, transferable and portable. Many different institutions, both public and private sector, operate these courses. They are, to a large extent, locally based and intended to address local conditions and technologies. This means a flexible, modular curriculum is needed. Modules prepared and shared about technologies and solutions (e.g. water and wastewater treatment systems, household treatments, source water protection, climate change adaptations, etc.) would provide building blocks for localised curriculum design. Educational institutions, private sector suppliers and water associations/ organisations would be the sources for this material.

Recent developments in providing an overview of water topics to graduate students who are pursuing studies on a particular aspect of water are proving successful in the institutions that are attempting this process. Examples are the Vienna University of Technology (2019) and the Collaborative Graduate Program at the University of Waterloo (2019). This might provide a different model for water studies at the graduate level. It might also have application at the baccalaureate level where an overview course on, for example, water management or IWRM, would be provided to students in various programmes associated with water studies (engineering, science, sociology, public health, medicine, etc.).

In an interesting development, the THE (Times Higher Education, 2019b) has recently introduced an impact ranking of universities based on a subset of the UN Sustainable Development Goals (SDG 3 – Good health and well-being, 4 – Quality education, 5 – Gender equality, 8 – Decent work and economic growth, 9 – Industry, innovation, and infrastructure, 10 – Reduced inequalities, 11 – Sustainable cities and communities, 12 – Responsible consumption and production, 13 – Climate action, 16 – Peace, justice and strong institutions and 17 – Partnerships for the goals).

The ranking system was complex, using different SDGs for different universities. A university's final score in the overall table is calculated by combining its score in SDG 17 with its top three scores out of the remaining 10 SDGs. SDG 17 accounts for 22 % of the overall score, while the other SDGs each carry a weighting of 26%. This means that different universities are scored based on a different set of SDGs, depending on their focus.

While they did not include SDG 6 on water, the rankings provide a different metric for examining universities – their impact on the subset of the SDGs. On a global scale, the top ten universities were (in decreasing rank order); University of Auckland (New Zealand), McMaster University and University of British Columbia (Canada; both equal 3rd); University of Manchester (UK), King's College London (UK), University of Gothenburg (Sweden), KTH Royal Institute of Technology (Sweden), University of Montreal (Canada), University of Bologna (Italy) and University of Hong Kong.

This ranking system could be used to rank universities by their activities in SDG 6 and any water-associated SDGs such as 3, 4, 11, 12 and 17 but where performance in SDG 6 is given greater weight.

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