



# Medical physics services in radiology and nuclear medicine in Africa: challenges and opportunities identified through workforce and infrastructure surveys

Christoph Trauernicht<sup>1</sup> · Francis Hasford<sup>2</sup> · Nadia Khelassi-Toutaoui<sup>3</sup> · Imen Bentouhami<sup>4</sup> · Peter Knoll<sup>4</sup> · Virginia Tsapaki<sup>4</sup>

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## Abstract

The International Atomic Energy Agency (IAEA) developed a staffing model to estimate the number of clinically qualified medical physicists (CQMP) that are required in an imaging facility, including diagnostic radiology and nuclear medicine. For the first time this staffing model was applied on a large scale across Africa. Within the framework of the IAEA African Regional Agreement (AFRA) Technical Cooperation (TC) project RAF6/053 entitled “Enhancing Capacity Building of Medical Physics to Improve Safety and Effectiveness of Medical Imaging (AFRA)”, a survey based on the IAEA staffing model was used to investigate the current CQMP workforce needs in imaging and radionuclide therapy in Africa in order to establish a baseline, identify gaps and suggest steps for improvement. The survey was open for five months, after which data verification was performed. 82 responses were received from 21 countries, including data from 97 diagnostic radiology and 40 nuclear medicine departments, as well as 75 interventional radiology departments and/or catheterization laboratories. Only 26.8% of centres employed an adequate number of CQMPs. The staffing model indicated that 134.3 CQMPs were required for these centres, but only 63 are currently employed in medical imaging and/or nuclear medicine at these centres. At least 11 countries do not have a single institution with an adequate number of CQMPs. Data analysis indicated that the number of radiology and nuclear medicine CQMPs is largely inadequate, at least by a factor of 20 in almost all countries in the region.

**Keywords** Medical physics · Nuclear medicine · Radiology · Imaging · Workforce

## 1 Strengths and limitations of the study

- The study applied a well-established imaging medical physics staffing model on a large scale across Africa.
- This is the first study to broadly investigate the staffing model across a whole region.

- The severe shortage of medical physicists in Africa was partially quantified.
- Results of the study will be biased towards centres that actually employ medical physicists, as these were the main respondents of the staffing survey.

## 2 Introduction

Medical imaging is technologically advanced, and the wide availability of services has resulted in a significant increase in applications and in global utilization [1, 2]. Medical physics deals with the application of physics principles to medicine and plays an important role in the prevention, diagnosis, and treatment of disease [3]. According to the International Labour Organisation, medical physicists are considered an integral part of the health workforce, with one of the listed tasks being “ensuring the

✉ Christoph Trauernicht  
cjt@sun.ac.za

<sup>1</sup> Division of Medical Physics, Tygerberg Hospital and Stellenbosch University, Cape Town, South Africa

<sup>2</sup> Medical Physics Department, School of Nuclear and Allied Sciences, University of Ghana, Accra, Ghana

<sup>3</sup> Medical Physics Department, Nuclear Research Centre of Algiers, Algiers, Algeria

<sup>4</sup> International Atomic Energy Agency, Vienna, Austria

safe and effective delivery of radiation (ionising and non-ionising) to patients to achieve a diagnostic or therapeutic result as prescribed by a medical practitioner” [4]. The importance of the role of the clinically qualified medical physicist (CQMP) in radiotherapy, diagnostic and interventional radiology, as well as nuclear medicine, is well described [5]. Of the 54 countries in Africa, only 6 presently have legislative recognition of medical physics as a health profession [6]. Lack of professional recognition has consequences on the staffing levels of medical physicists in medical imaging and radionuclide therapy. Low staffing levels, including in imaging medical physics can negatively impact the quality of services, resulting in increased waiting times for diagnostic scans, for instance [7]. The application of radionuclide therapies in nuclear medicine requires the skills of appropriately trained CQMPs for good practice and dosimetry, for instance [8, 9].

According to the recent Lancet Oncology Commission report on medical imaging and nuclear medicine, there is a lack of medical physicists to support diagnostic radiology and nuclear medicine theranostics in Low-and Middle-Income Countries (LMICs) [1]. In 2015, Atun et al. projected that in 2035 a total of 22,100 CQMPs would be needed to deliver effective radiotherapy in LMICs worldwide, and a call for action was made for 6000 additional CQMPs to be trained by 2025 [10]. However, the publication did not include the medical physics staffing needs of medical imaging and radionuclide therapy. Furthermore, systematic data on the availability of medical imaging and nuclear medicine equipment in LMICs has not been performed [1]. There are therefore scant data on the numbers and distribution of health professionals involved in providing imaging services—including CQMPs among others. The most recent estimate for the number of CQMPs in Africa is 1041, with about three-quarters working in radiotherapy [11]. Therefore, many imaging and radionuclide therapy facilities in Africa operate without any CQMPs.

In 2017, the International Atomic Energy Agency (IAEA) developed a comprehensive staffing model that estimates the required number of CQMPs in imaging and radionuclide therapy based on good practices, rather than just meeting minimum regulatory requirements [12]. Within the framework of the IAEA African Regional Agreement (AFRA) Technical Cooperation (TC) project RAF6/053 entitled “Enhancing Capacity Building of Medical Physics to Improve Safety and Effectiveness of Medical Imaging (AFRA)”, a survey based on the IAEA staffing model was used to investigate the current CQMP workforce needs in imaging and radionuclide therapy in Africa in order to establish a baseline, identify gaps and suggest steps for improvement.

### 3 Method & materials

The survey was opened for five months in 2020. The recommended IAEA methodology on medical physics staffing levels [12] in imaging and radionuclide therapy services is based on the requirements outlined in the International Basic Safety Standards—General Safety Requirements Part 3 [13] and explicitly considers the activities and factors pertaining to the roles and responsibilities of CQMPs as they are described in the IAEA Human Health Series Report No. 25 [5].

The survey was directed to health facilities in Africa and disseminated at the national level through different channels, including the IAEA TC project counterparts and the Federation of African Medical Physics Organizations (FAMPO) membership. The survey considered six key factors as described in the IAEA workforce methodology [12]:

- 1) number and complexity of equipment, devices, and rooms,
- 2) annual number of patient procedures,
- 3) radiation protection and safety related activities, including responsibilities related to occupationally exposed staff,
- 4) service-related factors (clinical audits, equipment specifications, quality management, radiation exposure management, etc.),
- 5) clinical training of other medical physicists and health professionals,
- 6) time dedicated to academic teaching, training, research, and continuous professional development.

The model estimates the number of required CQMPs by applying weighting factors in terms of full-time equivalent (FTE) CQMPs per input variable per key factor. If input data are not all available, the model will underestimate the staffing. An efficiency of scale factor takes into account that for large medical physics services, significant efficiencies can be achieved, for example combining the roles of radiology and nuclear medicine CQMPs into one service department or providing services to a group of hospitals, in order to share resources and know-how.

After receiving all responses, designated experts from the region were requested to verify the accuracy of data provided, correct any discrepancies or inconsistencies by communicating with the participating health facilities and obtain further clarification as required. Furthermore, the data from the respondents were compared to recently published estimates of imaging and nuclear medicine CQMPs in Africa [11].

## 4 Results

A total of 82 responses were received from 21 countries (Algeria, Benin, Burkina Faso, Cameroon, Congo, Cote d'Ivoire, Egypt, Ghana, Kenya, Libya, Mauritania, Morocco, Namibia, Niger, Nigeria, Senegal, South Africa, Sudan, Tanzania, Tunisia, and Uganda). Some respondents reported data from more than one imaging or nuclear medicine department. Thus, responses included data from 97 diagnostic radiology and 40 nuclear medicine departments, and also included data from 75 interventional radiology departments and/or catheterization laboratories.

The nuclear medicine imaging equipment reported were 32 single-photon emission computed tomography (SPECT) systems, 19 SPECT-Computed Tomography (CT) systems, 16 Positron Emission Tomography (PET)-CT systems and 4 cyclotrons. No PET-Magnetic Resonance Imaging (MRI) units were reported. Other nuclear medicine equipment included 11 thyroid uptake probes, 64 activity meters, 22 sentinel lymph node probes, 61 isotope generators and 26 gamma counters. Radiology equipment included 133 CT scanners, 311 fixed radiographic units, 80 mammography units, 214 fluoroscopy units, 126 interventional fluoroscopy units, 180 portable units, 61 intra-oral X-ray units, 24 dual energy X-ray absorptiometry (DEXA) units, 408 Computed Radiography (CR) detectors, 195 Digital Radiography (DR) units, 417 image display devices, 68 MRI scanners, 326 ultrasound units, 420 reading and printing devices, and 69 dark room wet processors. A total of 7.106 outpatient and 2.245 inpatient radionuclide therapy procedures were captured. The data show that digital imaging and radionuclide therapy are in widespread use.

As far as the annual patient workload is concerned, a total of 19.481 non-imaging procedures and 268.240 imaging procedures were reported in nuclear medicine. For radiological imaging, a total of 1.414.752 planar X-ray procedures, 604.597 CT examinations, and 70.366 interventional radiology and cardiology procedures were reported. Data show substantial patient workload in surveyed clinical institutions.

The CQMPs were responsible for the monitoring of 6.640 occupationally exposed staff, which implies that the CQMPs were also acting as radiation protection or safety officers in many hospitals, adding an additional workload to the routine clinical duties.

Based on the survey input related to time dedicated to education and professional matters, the ratio of supervisor to residents exceeded the recommended 1:2 [14] in some centres in five countries (Algeria, Egypt, Libya, Mauritania, Tunisia). Three countries (Nigeria, Sudan, Tanzania) indicated that some medical physics residents were not supervised by on-site CQMPs.

Each centre applied the IAEA staffing algorithm [12] to determine whether the number of CQMPs met the required needs. The results show that only 22 of 82 centres (26.8%) employed an adequate number of CQMPs. 63 CQMPs are dedicated to medical imaging and/or nuclear medicine, whereas the staffing model indicated that 134.3 CQMPs were required for these centres. 38 medical physics residents are being trained across the centres that were surveyed.

Figure 1 shows the number of respondents per country, colour coded to indicate centres with an adequate (green) or inadequate (red) number of CQMPs. It should be noted that the survey does not indicate whether the facilities are adequate to cover the national population medical imaging and nuclear medicine needs, but only shows whether the number of CQMPs is adequate based on the six factors used by the IAEA staffing model. The figure shows that at least 11 countries do not have a single institution with an adequate number of CQMPs.

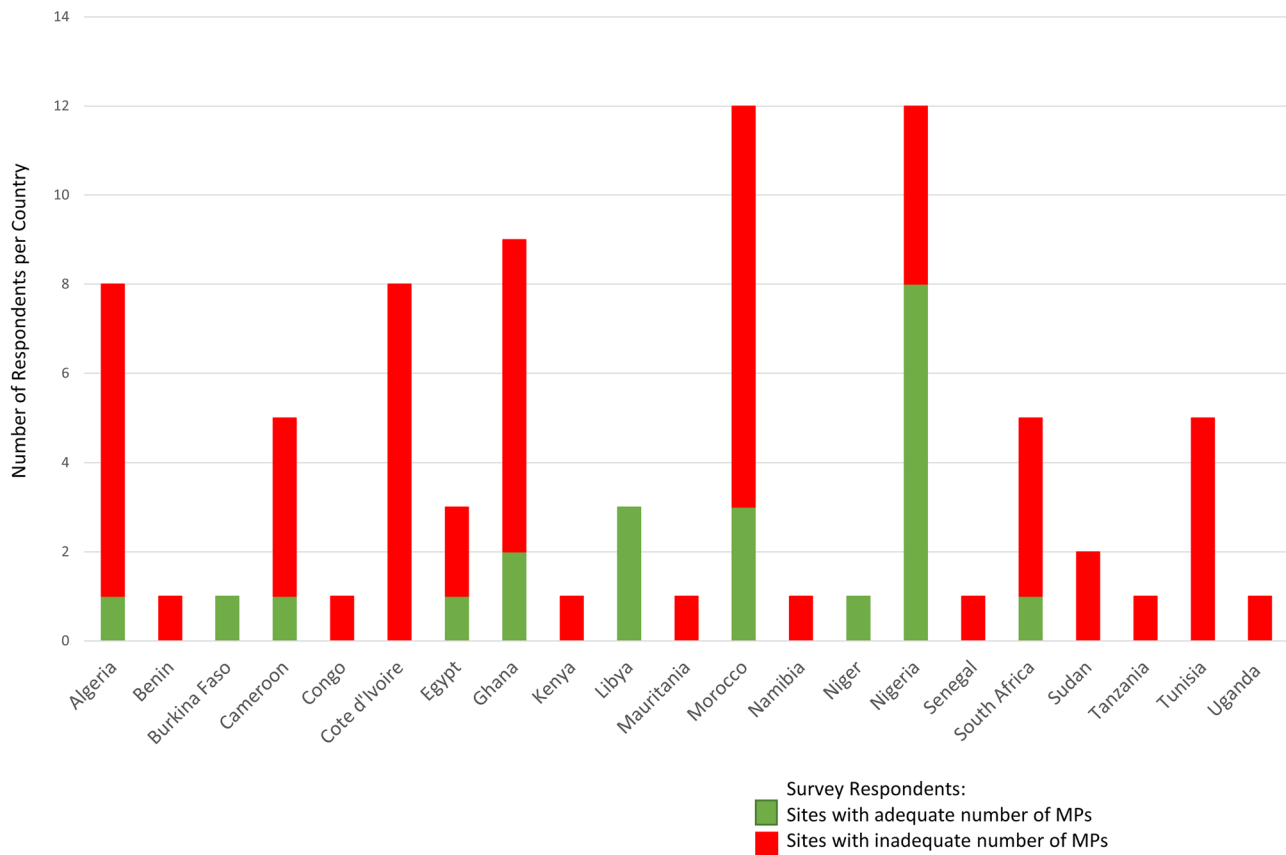
The country summary of the number of CQMPs that are recommended by the IAEA algorithm (blue) versus the available number (orange) is shown in Fig. 2. These results clearly indicate that in most of the centres surveyed, the number of CQMPs is insufficient based on the services that were reported.

## 5 Discussion

In a recent publication [11], dedicated to the development of medical physics in Africa, several countries provided national data on the status of education and training programmes in medical physics [15–22]. The number of imaging and nuclear medicine medical physicists per country was extracted from the publication [11] and is shown in Fig. 3. The 63 CQMPs included in the survey results from this work are therefore a subset of the total number of 251 imaging and nuclear medicine medical physicists in Africa.

The International Organization for Medical Physics collected data in 2018 on the global imaging and radiotherapy medical physics workforce [23]. In that survey, 18 African countries responded, 13 of which were also included in a survey in 2019 [11]. The changes in the medical physics staffing that were reported from these 2 surveys are shown in Table 1. The data indicate that the number of CQMPs increased in almost all countries in Africa between 2018 and 2019.

Data of 32 African countries obtained from Ige et al. [11], were then used to determine the number of imaging and nuclear medicine CQMPs per million population in Africa (population data from [24]). As seen in Fig. 4, it was found that only one country (Egypt) has more than 1 CQMP supporting imaging per million inhabitants. Four countries (Libya, Mauritania, Namibia, South Africa) have between



**Fig. 1** The CQMP staffing levels that were reported by the centres that responded to the survey from 21 African countries. The adequacy of staffing levels is indicated in relation to the level recommended by the activity-based IAEA staffing model [12]

0.5–1 imaging and nuclear medicine medical physicists per million population. In all remaining countries, the ratio is less than 0.5 imaging and nuclear medicine CQMPs per million.

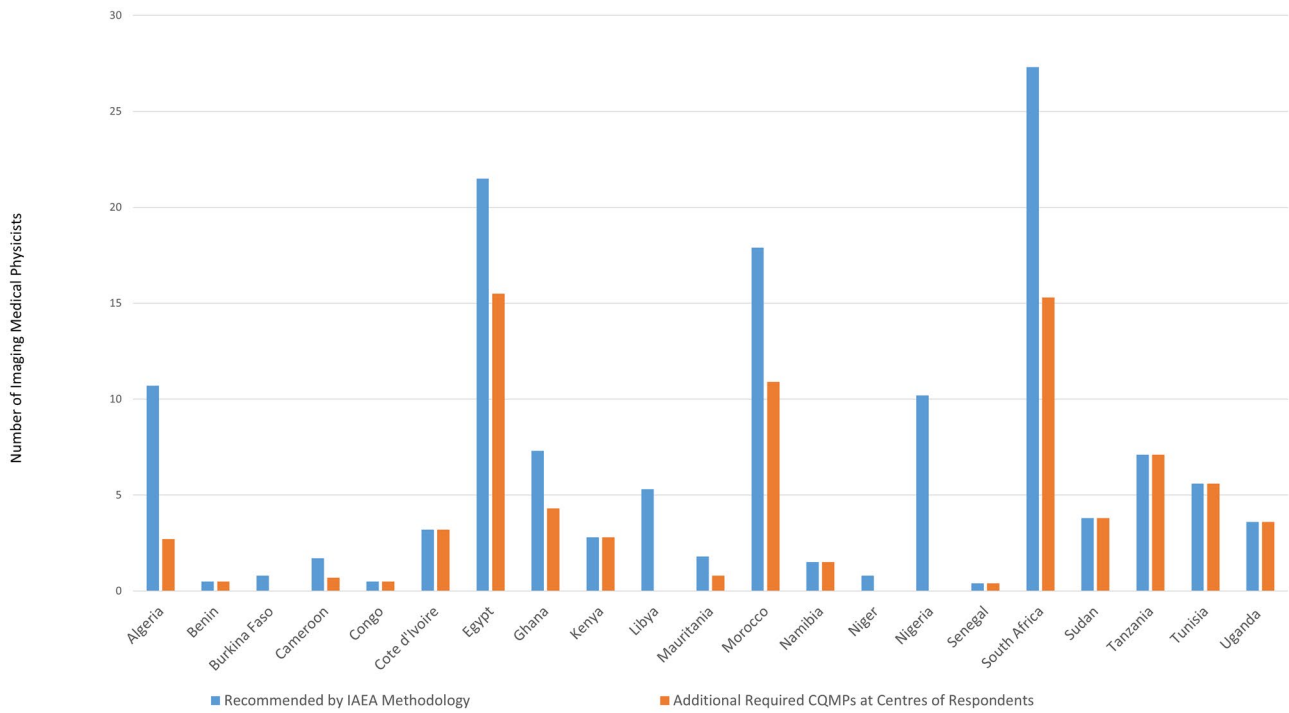
Owing to the limited number of respondents to this survey, it is difficult to extrapolate the total number of CQMPs required to support medical imaging in Africa. The responses of the IAEA staffing survey were correlated with published imaging and nuclear medicine equipment data to determine the staffing shortfall. Eight responses were received from Algeria, three from Egypt, nine from Ghana, twelve each from Morocco and Nigeria, five from South Africa and one from Tanzania. Published datasets from these 7 African countries [15, 17, 19, 21, 25–27] were consulted to estimate the availability of radiology equipment in these countries in order to provide some reasonable estimates of needs. Nuclear medicine equipment data was obtained from the IAEA IMAGINE database [28]. These data are represented in Table 2.

The extrapolation does not take into account the entire spectrum of the CQMP's roles and responsibilities, but only equipment related factors; nevertheless, it gives some insight into the dire need for CQMPs.

For Algeria, the survey covered 64 of about 3000 X-ray units (2.1%), 7 of 281 mammography units (2.5%) and 20 of 574 CT scanners (3.5%). For nuclear medicine, 3 SPECT (8.6%) and 1 PET/CT (16.7%) was reported. A total of eight CQMPs (corresponding to a 47% response rate of the imaging and nuclear medicine medical physicists working in the country) working at the eight centres responded (2.7 less than recommended by the algorithm). At least a 20-fold increase in the number of imaging and nuclear medicine CQMPs is needed to support the equipment in the country.

For Egypt, these numbers were 32 of 3852 X-ray units (0.8%), 9 of 185 mammography units (4.9%) and 12 of 725 CT scanners (1.7%). For nuclear medicine, 4 SPECT (5.4%) and 7 PET/CT (35.0%) scanners were reported. The three Egyptian centres required 21.5 FTE CQMPs, but only 6 FTE CQMPs were reported.

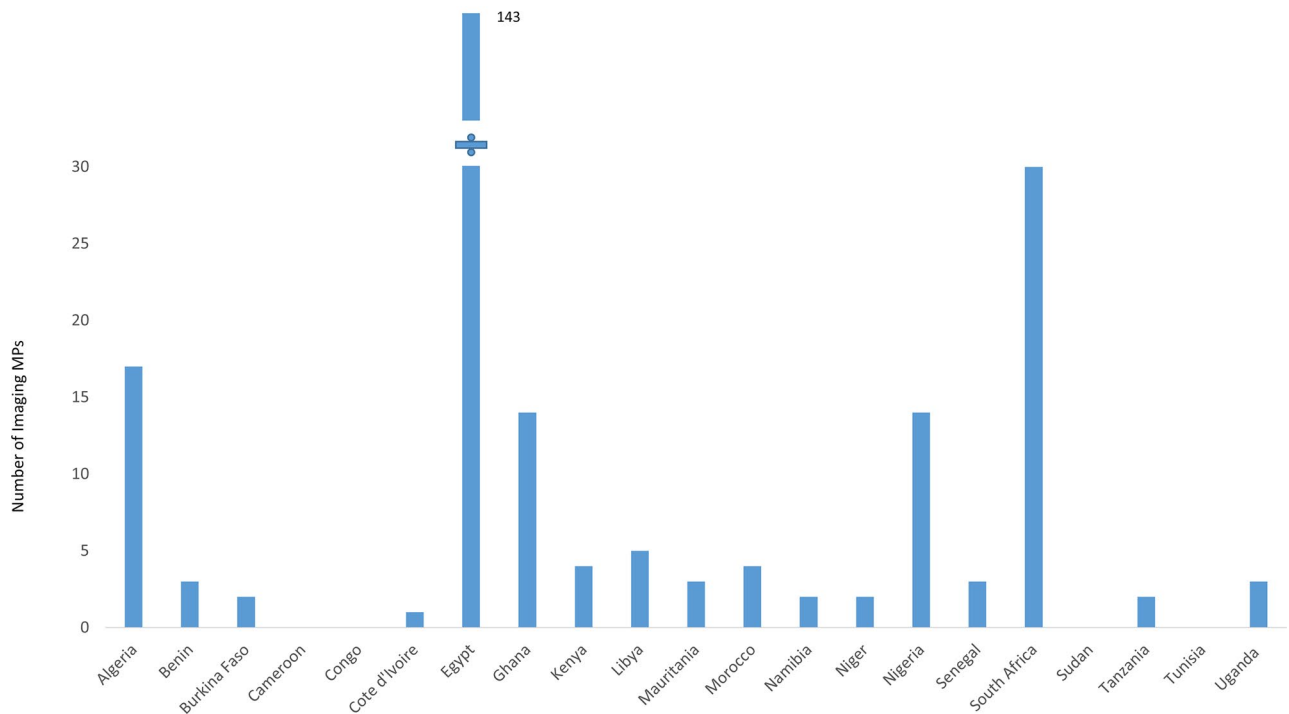
For Ghana, 45 of 322 X-ray units were included (14.0%), 12 of 18 fluoroscopy units (66.7%), 8 of 17 mammography units (47.1%) and 14 of 28 CT scanners (50.0%). Only one SPECT system was reported in the survey. The staffing algorithm recommended 7.3 FTE CQMPs for the data supplied, but only three FTE CQMPs were available at these



**Fig. 2** Recommended medical physics staffing levels for imaging and nuclear medicine obtained from the 21 African countries that responded to the survey, indicating the shortfall in each case

centres. Apart from X-ray units, the survey covered around half of the existing imaging and nuclear medicine equipment, requiring 7.3 FTE CQMPs. Ghana currently employs

14 imaging and nuclear medicine CQMPs [11], which is an indication that the existing equipment is covered by the existing CQMP workforce.



**Fig. 3** Number of imaging and nuclear medicine medical physicists in African countries extracted from a 2019 survey (Total Number: 251) [11]

**Table 1** Percentage change in imaging and therapy medical physics numbers from previously published global workforce surveys

	Global workforce (2018) [23]	FAMPO data (2019) [11]	Percentage change from 2018–2019
Algeria	36*	129	258.3*
Cameroon	2	2	0.0
Egypt	200	374	87.0
Ghana	58	58	0.0
Kenya	4	7	75.0
Morocco	36	61	69.4
Namibia	6	6	0.0
Nigeria	100	100	0.0
Senegal	2	3	50.0
South Africa	185**	136	(-26.5)**
Sudan	28	28	0.0
Tanzania	4	4	0.0
Tunisia	17	37	117.6

\*This number corresponds to the number of CQMPs in 2006 but was the one quoted in paper in 2018

\*\*2018 data from South Africa is the member number of the South African Association of Physicists in Medicine and Biology, which also includes retired members, institutional members, affiliated members, and radiobiologists. The association had 113 full members in 2018 and increased to 127 full members at the time of the survey

For Morocco, the survey covered 73 of 4500 X-ray units (1.6%), 11 of 110 mammography units (10.0%) and 24 of 360 CT scanners (6.7%). For nuclear medicine, 1 SPECT and 1 SPECT/CT (7.1%) system was reported. The staffing algorithm indicated a shortage of 11.5 FTE CQMPs and indicated that over 90% of the imaging equipment is not supported by CQMPs.

For Nigeria, the survey covered only 47 X-ray units of approximately 3000 in the country (1.6%), 11 of 60 mammography units (18.3%) and 13 of 150 CT scanners (8.7%). For nuclear medicine, 1 SPECT and 1 SPECT/CT system (66.7%) was reported. The Nigerian centres reported adequate staffing in 8 of the 12 centres according to the IAEA staffing model. However, this survey included all imaging and nuclear medicine CQMPs from Nigeria. With only 1.6% of X-ray units included, about 20% of mammography units and less than 10% of all CT scanners known to be installed in the country, the staffing levels are significantly below the needs.

For South Africa, the survey reported on CQMP staffing levels for 93 of approximately 1844 licensed X-ray units (5.0%), 7 of 263 licensed mammography units (2.7%), 15 of 265 licensed CT scanners (5.7%) and 6 of 154 licensed MRI scanners (3.9%). However, the survey obtained information for 182 of 350 fluoroscopy units (52.0%); 146 of these units are installed in one hospital group. Data were

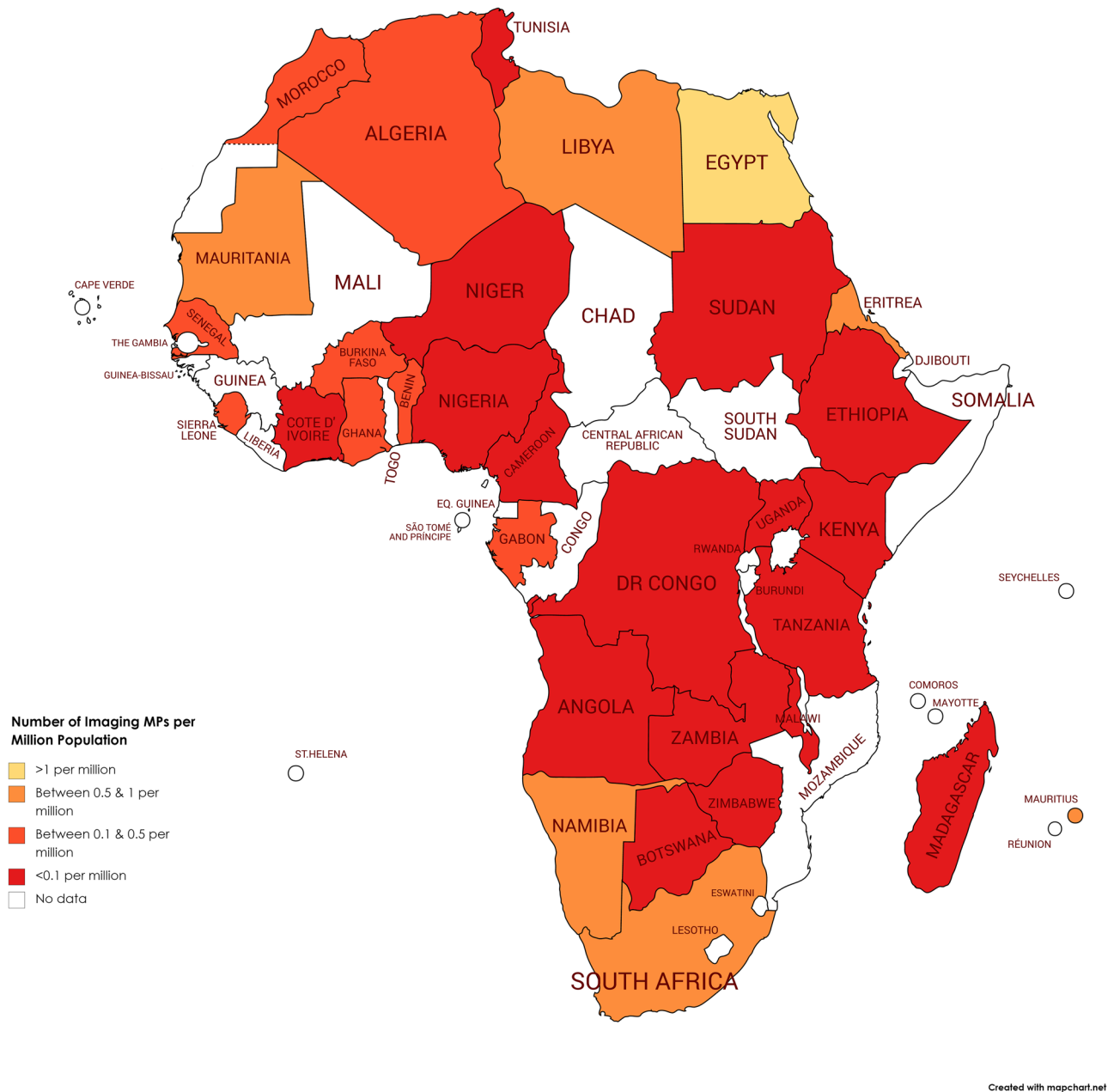
reported on 14 of approximately 90 gamma cameras / SPECT / SPECT-CT units in the country (15.6%) and 3 of 10 PET-CT scanners (30.0%). The responses returned a need for 27.3 FTE CQMPs as per the staffing algorithm but only 12 FTE CQMPs were reported. Only one of the five centres was adequately staffed. Assuming that 27.3 FTE CQMPs service 10% of the current imaging and nuclear medicine needs, then approximately 270 imaging and nuclear medicine CQMPs are required to cover existing services in South Africa.

For Tanzania, the single survey response was as follows: 5 of 405 X-ray units were included (1.2%), 2 of 45 fluoroscopy units (4.5%), 1 of 14 mammography units (7.2%), 1 of 19 CT scanners (5.3%) and 3 SPECT and 1 SPECT/CT (100%). The staffing model required 7.1 FTE CQMPs for the one centre that responded; however, none were employed there, and only two nationally [7]. Two thousand (2000) patient exposure calculations were reported for high-dose procedures per year. Nevertheless, a 20-fold increase in CQMP numbers would not offer adequate staffing levels to support the existing number of imaging and nuclear medicine equipment in Tanzania.

The World Health Organization (WHO) recognizes basic diagnostic imaging services as vital to any healthcare system and suggests that one basic radiographic X-ray system and ultrasound unit for every 50,000 people would address 90% of global imaging needs [25, 29]. Based on Africa's population of approximately 1.3 billion, this equates to 26,000 X-ray units needed for basic service delivery, and according to the IAEA staffing model, these units alone would require 266 FTE CQMPs for periodic performance testing and quality control, excluding any other factors (radiation safety, patient workload levels, etc.).

According to Ige et al. [11], there are 137 CQMPs employed in diagnostic radiology in Africa, and 124 in nuclear medicine. Egypt employs more than half of imaging and nuclear medicine CQMPs on the continent and only 119 FTE imaging and nuclear medicine CQMPs cover the needs of the other approximately 1.2 billion population in Africa.

The data in this survey was supplied by CQMPs providing radiology and/or nuclear medicine medical physics services and therefore did not capture data from centres without CQMP support. The survey returned some basic data on clinical medical physics training, which is not performed at all centres. Unfavourable supervisor-to-residents ratios (< 1:2) [14], or centres with residents without supervisors, will significantly affect the quality of medical physics services. National or regional academic and clinical training programmes are needed to increase the number of CQMPs in Africa. To this end, IAEA regional TC projects supporting radiotherapy and medical imaging (radiology and nuclear medicine) physics developed a harmonized syllabus for the



**Fig. 4** Estimated number of imaging and nuclear medicine medical physicists per million population in Africa

education of medical physicists in Africa [14]. The syllabus includes both academic and clinical training components. However, many countries in Africa have not initiated national programmes [11].

Considerable efforts remain to be made in most of the countries of the region to address the lack of CQMPs and to sustain the profession of medical physicist, including those in radiology and nuclear medicine. This necessarily involves the establishment of a framework for the recognition of the profession of medical physicist by the health

authority, which in turn requires recognition of national or regional academic and clinical training programmes in medical physics. The IAEA recently published guidance for the certification of CQMPs [30], including criteria for the establishment of national certification bodies, processes for the registration of CQMPs and recommendations for CQMP continuous professional development.

National medical physics associations and international organisations also play an important role in the promotion of the medical physics profession.

**Table 2** Radiology and nuclear medicine equipment availability in 7 African countries obtained from other sources as indicated

Year [Ref]	Country	Population [million]	No. of units per million population						
			General X-Ray	Fluoroscopy	Mammography	CT	MRI	PET	SPECT, SPECT/CT (2020 data from IMAGINE)[28]
2014 [25]	Tanzania	44.9	9.020	1.00	0.31	0.42	0.09	0.00	0.05
2015 [26]	South Africa	53.0	34.80	6.60	4.96	5.00	2.90	0.16	1.47
2016 [27]	Ghana	25.0	12.88	0.72	0.68	1.12	0.00	0.00	0.07
2019 [15]	Algeria	43.4	69.11	1.15	6.47	13.22	3.46	0.02	0.81
2019 [17]	Egypt	99.2	38.83	6.27	1.86	7.31	2.32	0.52	0.74
2019 [19]	Morocco	35.0	128.57	1.71	3.14	10.29	1.14	0.29	0.77
2019 [21]	Nigeria	201.0	14.93	0.04	0.30	0.75	0.42	0.00	0.01

## 6 Conclusion

This is the first study to broadly investigate the radiology and nuclear medicine CQMP workforce based on the IAEA methodology at a regional level. The results of the survey show that the number of CQMPs in Africa is insufficient. It is also evident that an extrapolation to determine the estimated number of CQMPs to cover current services has very large uncertainties. This survey focused only on the staffing needs at the facility level and not at the country level. It should be noted that the number of CQMPs per million population is not an indication of the sophistication or size of an imaging service infrastructure, or how evenly services are divided across a country, or even within a single city. From the data analysis, the number of radiology and nuclear medicine CQMPs is largely inadequate, at least by a factor of 20 in almost all countries in the region.

In order to accelerate reasonable capacity building for CQMPs in Africa, CQMPs are encouraged to initiate national clinical training programmes using the resources that are available, in compliance with national, international, or regional guidelines, recommendations and standards.

Several steps can be undertaken to try to improve the situation such as:

1. Inclusion of CQMPs in the clinical routine: An increased awareness of the roles and responsibilities of a CQMP in diagnostic radiology and nuclear medicine in the everyday clinical routine will encourage the employment of CQMPs.
2. Regulatory infrastructure: Regulations in compliance with the International Basic Safety Standards [13] to support the recognition and employment of CQMPs.
3. Professional certification for CQMPs: Certification of CQMPs as health professionals should be encouraged to promote recognition of medical physics.

4. The number of academic and clinical training programmes must be expanded to guarantee a steady increase in the number of CQMPs in the region. Furthermore, graduates from these programmes, or those training abroad, must be employed as CQMPs upon return to their countries, encouraged to disseminate their knowledge and in turn set up training programmes in facilities, if resources allow and protected time is provided for this responsibility.

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**Author contributions** CT: Formal analysis, data processing, visualization, writing original draft, review & editing FH: Data collation, validation and processing, formal analysis, writing – review & editing NT-K: Data validation, formal analysis, writing – review & editing IB: Conceptualization, administration, writing – review & editing PK: Conceptualization, planning & co-ordination, writing – review & editing VT: Conceptualization, planning & co-ordination, supervision, writing – review & editing.

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**Data availability** The raw data is available from the corresponding author.

**Code availability** Not applicable.

## Declarations

**Ethical requirements** All authors comply with Springer's ethical policies. An ethics waiver was applied for through Stellenbosch University.

**Statement of informed consent** Not applicable.

**Statement of human and animal rights** Not applicable.

**Conflicts of interest** None of the authors have any conflicts of interest to declare.

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## References

- Hricak H, Abdel-Wahab M, Atun R, Lette MM, Paez D, Brink JA, et al. Medical imaging and nuclear medicine: a Lancet Oncology Commission. *Lancet Oncol*. 2021;22(4):E136-172. [https://doi.org/10.1016/S1470-2045\(20\)30751-8](https://doi.org/10.1016/S1470-2045(20)30751-8).
- United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 2008 Report to the General Assembly Sources and effects of ionizing radiation. New York: Medical radiation exposures; 2013.
- Meghzifene A. A call for recognition of the medical physics profession. *Lancet*. 2012;379(9825):1464-5.
- International Labour Office. International Standard Classification of Occupations (ISCO-08) – Structure, group definitions and correspondence tables. 2012, Geneva. ISBN 978-92-2-125953-4 (web pdf). Available from [https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms\\_172572.pdf](https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_172572.pdf) (last accessed on 9th September 2021) 2021.
- International Atomic Energy Agency. Roles and Responsibilities, and Education and Training Requirements for Clinically Qualified Medical Physicists, Human Health Series No. 25, IAEA, Vienna 2013.
- Ige T. Status of Medical Physics in Africa. *African Journal of Medical Physics (AJMP)*. 2021;3(Supplement):A1-22.
- Institute of Physics and Engineering in Medicine. Patients at risk of waiting longer for scans due to staff shortages. IPEM Newsletter: available at <https://www.ipem.ac.uk/NewsExternalAffairs/LatestNews/TabId/366/ArtMID/1595/ArticleID/317/Patients-at-risk-of-waiting-longer-for-scans-due-to-staff-shortages.aspx> (last accessed on 9th September 2021) 2021.
- Bodei L, Mueller-Brand J, Baum R, Pavel M, Hörsch D, O'Dorisio M, et al. The joint IAEA, EANM, and SNMMI practical guidance on peptide receptor radionuclide therapy (PRRT) in neuroendocrine tumours. *Eur J Nucl Med Mol Imaging*. 2013;40:800. Available from: <https://doi.org/10.1007/s00259-012-2330-6>
- Trauernicht C, du Toit P. Peptide receptor radionuclide therapy of neuroendocrine tumours: how important is internal dosimetry?. *S Afr J Surg*. 2019;57;1 [ISSN 2078-5151].
- Atun R, Jaffray D, Barton M, Bray F, Baumann M, Vikram B, et al. Expanding global access to radiotherapy. *Lancet Oncol*. 2015;16:1153-86.
- Ige T, Hasford F, Tabakov S, Trauernicht C, Rule A, Azangwe G, et al. Medical physics developments in Africa - status, education, challenges, future. *Medical Physics Int J. Special Issue: History of Medical Physics* 2020;3:303-16.
- IAEA Human Health Reports No. 15: Medical physics staffing needs in diagnostic imaging and radionuclide therapy: an activity-based approach. Vienna: IAEA; 2018.
- European Commission, Food and Agriculture Organization of the United Nations, International Atomic Energy Agency, International Labour Organization, OECD Nuclear Energy Agency, Pan American Health Organization, United Nations Environment Programme, World Health Organization, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards: General Safety Requirements Part 3, No. GSR Part 3, IAEA, Vienna (2014).
- IAEA, Academic and clinical training programmes and portfolios for the regional training in medical physics. 2019; Available from [https://humanhealth.iaea.org/HHW/MedicalPhysics/TheMedicalPhysicist/EducationandTrainingRequirements/EducationalRequirements/Harmonized\\_syllabus\\_for\\_Medical\\_Physicists\\_training\\_in\\_Africa.pdf](https://humanhealth.iaea.org/HHW/MedicalPhysics/TheMedicalPhysicist/EducationandTrainingRequirements/EducationalRequirements/Harmonized_syllabus_for_Medical_Physicists_training_in_Africa.pdf) [accessed on 9th September 2021].
- Toutaoui A, Khelassi-Toutaoui N, Brahimi Z. Medical physics education and training in Algeria. *Med Phys Int J*. 2019;7(3):284-5.
- Besbes M, Bensalem L, Nasr C. Medical physics education and training in Tunisia. *Med Phys Int J*. 2019;7(3):286-7.
- Deiab N, Elshahat K, Attalla E. Medical physics education and training in Egypt *Medical Physics*. *Int J*. 2019;7(3):288-9.
- Azangwe G, Ndlovu D, Thatha T, Mhathiwa L, Mhukayesango E. Medical physics education and training in Zimbabwe. *Med Phys Int J*. 2019;7(3):275-6.
- Saikouk H, Ou-Saada I, Bentayeb F, Boutayeb S, Eddaoui K. Medical physics status in Morocco: education, training and evolution. *Med Phys Int J*. 2019;7(3):282-3.
- Hasford F, Inkoom S, Kyere A, Schandorf C, Amuasi J. Medical physics education and training in Ghana. *Med Phys Int J*. 2019;7(3):279-81.
- Ige T, Aweda M, Adewole M. Medical physics education and training in Nigeria. *Med Phys Int J*. 2019;7(3):277-8.
- Trauernicht C, Rule A. Medical physics education and training in South Africa. *Med Phys Int J*. 2019;7(3):271-4.
- Tsapaki V, Tabakov S, Rehani M. Medical physics workforce: A global perspective. *Phys Med*. 2018;55:33-9. <https://doi.org/10.1016/j.ejmp.2018.10.012>.
- Worldometer - African Countries by population. Available from: <https://www.worldometers.info/population/countries-in-africa-by-population/> [Accessed on 9th September 2021].
- Ngoya P, Muhogora W, Pitcher R. Defining the diagnostic divide: an analysis of registered radiological equipment resources in a low-income African country. *Pan Afr Med J*. 2016;25:99. <https://doi.org/10.11604/pamj.2016.25.99.9736>.
- Kabongo J, Nel S, Pitcher R. Analysis of licensed South African diagnostic imaging equipment. *Pan Afr Med J*. 2015;22:57. <https://doi.org/10.11604/pamj.2015.22.57.7016>.
- Amuasi J, Kyere A, Schandorf C, Fletcher J, Boadu M, Addison E, et al. Medical physics practice and training in Ghana. *Phys Med*. 2016;32(6):826-30.
- IMAGINE – IAEA Medical imAGInG and Nuclear mEdicine global resources database, <https://humanhealth.iaea.org/HHW/DBStatistics/IMAGINE.html> [accessed 11 Nov 2020]
- World Health Organization. Needs assessment for medical devices; 2011. Available from: <https://apps.who.int/iris/handle/10665/44562>. [accessed on 9th September 2021].
- International Atomic Energy Agency (IAEA). Guidelines for the Certification of Clinically Qualified Medical Physicists. Training Course Series No. 71, IAEA, Vienna (2021).

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