

***Cryptosporidium* and *Giardia lamblia* Epidemiology in Middle Eastern Countries: study of the proliferation problem in the aquatic environment**

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Abstract. The aim is to present a summarized study of the available literature on *Cryptosporidium* and *Giardia lamblia* for Middle Eastern countries, in order to identify trends in human cryptosporidiosis and childhood morbidity, and to raise awareness among residents. This is necessary in order to address the gap in preventive measures required to mitigate the overall effect attributed to associated illness and its impact in the already water stressed Middle Eastern countries. To assess seroprevalence of *Cryptosporidium* and *Giardia lamblia* in Middle Eastern countries systematic review was carried out based on online articles published from 2010-2018. PubMed, Web of Science, Google Scholar, Science Direct, Scopus, World Bank and WHO report and scientific database were explored. The current study highlights the existing subsequent epidemiology, its seroprevalence distribution, genetic diversity across Middle Eastern countries since 2009. This study therefore will provide the platform for future research work and development in comprehending *Cryptosporidium* and *Giardia lamblia* epidemiology in Middle Eastern countries. It was found that lack of awareness, personal hygiene and sanitation facilities, poverty, indiscriminate eating habits are favourable infestation conditions for *Cryptosporidium* and *Giardia lamblia* infections. The prevalence for both *Cryptosporidium* and *Giardia lamblia*, is higher in developing countries as compared to developed countries. The originality is that it is the only study of its kind in the region, as such studies are still lacking in Middle East countries as compared to other European, Asian, American continents and countries.

Keywords: water resources, tap water contamination, epidemiology, hygiene and sanitation, protozoan parasites, seroprevalence, childhood morbidity.

1. Introduction

Water resources (surface and underground fresh water) must support the vital activity of humans, plants and animals on the planet. However, due to the negative technogenic influence (Ziarati et al., 2021; Khan et al., 2019a; Khan et al., 2019b; Deineka et al., 2018), as well as due to climatic factors (Dang et al., 2018; Liu et al., 2017), in some countries there are problems with the provision of water supply, safe for consumption.

There are many literatures on protozoan parasites around the world published in peer reviewed journal. However, literature from Middle Eastern countries is still lacking even though it is among one of the most water stressed region in the world. The pathogen entry to

water resources is mainly attributed to improper water facilities, insufficient water purification processes and in water scarce region like Middle East water contamination and entry of protozoan parasites like *Cryptosporidium* and *Giardia lamblia* highly is highly susceptible (Mazzoni & Zaccagni, 2019). This review has covered available literature on *Cryptosporidium* and *Giardia lamblia* for Middle Eastern countries. This summarized study will be one of its kind in the region as such studies are still lacking in Middle Eastern countries as compared to other European, Asian, American continents and countries (Xu & May, 2017; Michel et al., 2012; Terink et al., 2013). Figure 1 presents the map of Middle Eastern countries covered in this study.

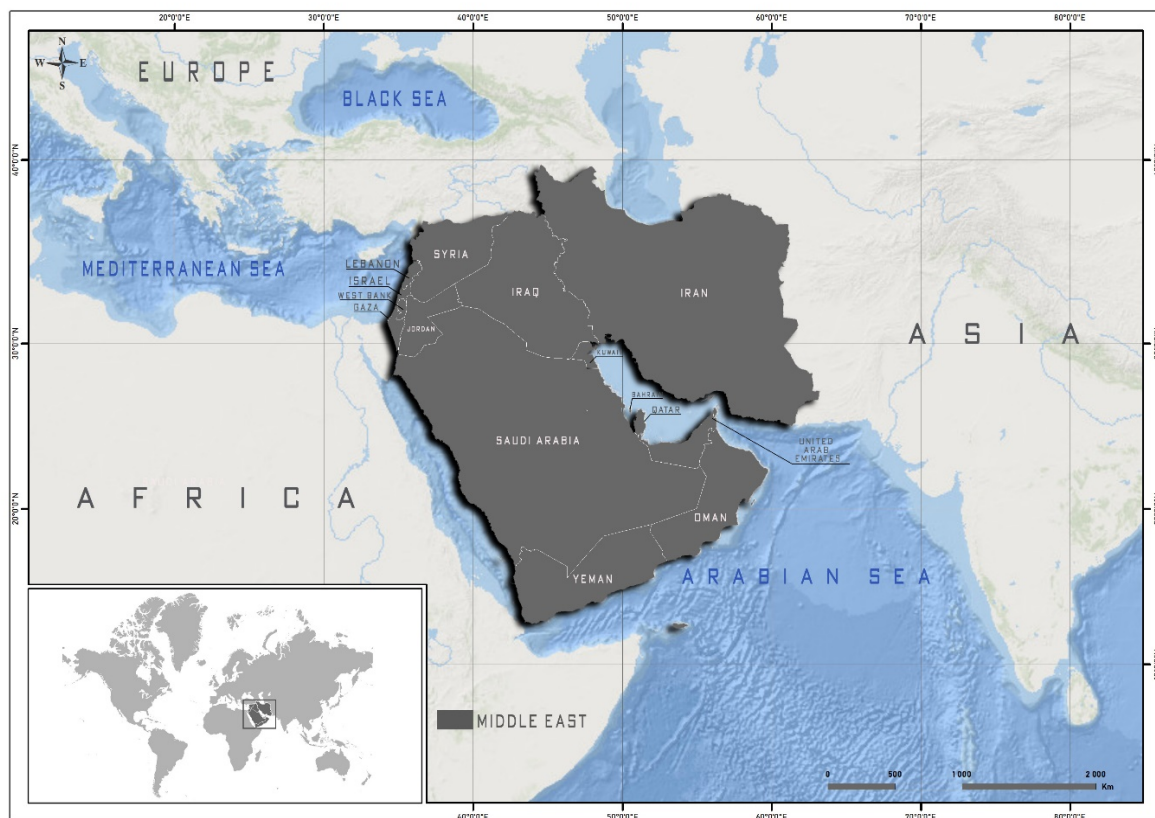


Figure 1. Map of Middle Eastern countries covered in this study

The second primary cause of death among children less than five years is diarrhoea. Each year about 525,000 deaths among kids are attributed to diarrhoea. Globally there are about 1.7 billion cases of diarrhoea each year (WHO, 2019; U.S.H.O.F., 2016). In children below five years mortality (no. of deaths) for the year 2016 in Middle Eastern countries was 1936 (Iraq), 870 (Iran), 117 (Jordan), 1 (Kuwait), 17 (Lebanon), 10 (Oman), 1 (Qatar), 87

(Saudi Arabia), 1519 (Syria), 5 (United Arab Emirates) and 3702 (Yemen) (WHO, 2019; U.S.H.O.F., 2016). *Cryptosporidium* is reported secondary cause of diarrhoea only behind rotavirus. The leading parasitic protozoa causing waterborne enteric disease outbreaks at global level are *Cryptosporidium* and *Giardia lamblia* (Efstratiou et al., 2017). Originating from faeces of infected hosts they can be transmitted to new hosts via oral-faecal route upon contact with contaminated soil, water, feed and food. Hence, the study has focused on each of this water borne protozoa.

2. Materials and Methods

In order to assess seroprevalence of *Cryptosporidium* and *Giardia lamblia* in Middle Eastern countries systematic review was carried out based on online articles published from 2010-2018. PubMed, Web of science, Google Scholar, Science Direct, Scopus, World Bank and WHO report and scientific database were explored to retrieve necessary information for assessment. The present review was performed using keywords, *Cryptosporidium*, *Cryptosporidiosis*, *Giardia lamblia* combined or as individual country for Middle Eastern countries. The literature distribution of *Cryptosporidium* and *Giardia lamblia* is presented in Figures 2 and 3.

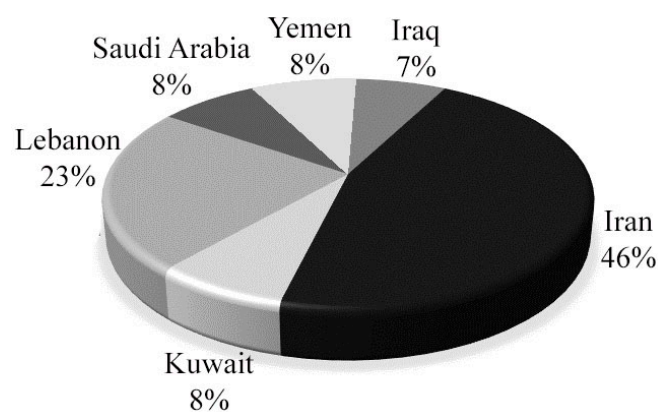


Figure 2. *Cryptosporidium* literature distribution in Middle Eastern countries

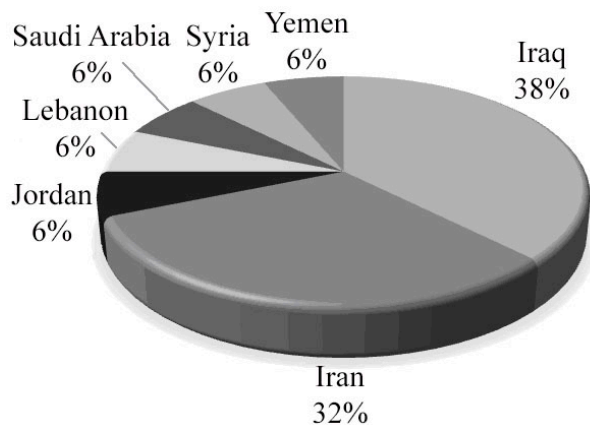


Figure 3. *Giardia lamblia* literature distribution in Middle Eastern countries

3. Results and Discussion

This study covered articles and reports published for Middle Eastern countries covering *Cryptosporidium* and *Giardia lamblia*. These studies were conducted based on host (Human (Infants, Children, Women, Elderly) or animals (bird, camel, sheep) for the identified *Cryptosporidium* and *Giardia lamblia*.

3.1. *Cryptosporidium* Seroprevalence in Middle East

The data obtained from literature was summarized and represented in Table 1. Majority of the studies infers that *C. hominis* and *C. parvum* are the primary *Cryptosporidium* species responsible for causing infection in Human population. In study from Kuwait, *C. parvum* was the dominant species present with its subtype prevailing in order of I2a, I2d and I2c, while *C. hominis* followed with its subtype in prevailing order of I2d, I2a and I2e, inferring that genetic of parasite may play a major role in human cryptosporidiosis (Iqbal et al., 2011). Other species studies did not identify genetics or sub species of *Cryptosporidium* species. This is primarily being due to non-uniform testing procedure and standards adopted across Middle Eastern countries along with lack of standardized infrastructure. PCR (Polymerase Chain Reaction) yielded highest rate of detection as compared to ELISA (Enzyme-linked immunosorbent assay) and MZN (modified ziehl neelsen) staining method. From three techniques; Direct Fluorescent Antibody (DFA), modified acid fast stain and Immune Card techniques used to detect *C. parvum*, modified acid fast stain performed better (Ali et al., 2014). Again, results of studies have variation depending upon the method used to identify genotype of *Cryptosporidium*.

In study from Kuwait; children in 4-8 years of age group are mostly affected (Iqbal et al., 2011). Iran reported, *Cryptosporidium* prevalence of 9.7% was higher in children under 4-5 years of age with *C. parvum* prevailing in diarrheic children (Mahdavi Poor et al., 2015; Dabirzadeh et al., 2017). Even the study in 2011 reported similar results of *C. parvum* dominance over other species of *Cryptosporidium* (Taghipour et al., 2011). Lebanon reported prevalence rate of children was 10.4%, and was peaking in children under five years of age with 11% (Osman et al., 2017; Osman et al., 2018; Osman et al., 2015). In Iraq; or children also Acid fast (AF) staining technique provided better results than immune cards (Ali et al., 2014).

The *Cryptosporidiosis* in Out patients, Hospitalized patients, immune suppressed patients are attributed to *C. hominis* and *C. parvum*. In Iran; among gastroenteritis patient, *Cryptosporidium* was reported for only 2.3% (Gholami et al., 2014). In Lebanon the reported prevalence rate was 21% in adenocarcinoma patients, 11% in symptomatic patients (Osman et al., 2017; Osman et al., 2018; Osman et al., 2015). *Cryptosporidium* was reported not to cause any effect on gastroenteritis but children under 10 year reported highest infection percent (Ghenghesh et al., 2016). Lack of data on age group in studies made it difficult to attribute any *Cryptosporidium* subspecies to specific age group. However, in displaced population (refugees) *C. parvum* was reported to be the cause of *Cryptosporidiosis*.

Among adult birds wild and domestic *C. meleagridis*, (IIIgA22G3R1) and *C. baileyi* (IIIgA23G2R1) were identified as *cryptosporidiosis* causing protozoa. While *C. bovis*, *C. ryanae* and *C. parvum* were identified as cause of *cryptosporidiosis* in Juvenile calves. *C. parvum* has been identified as causing infection in humans which was also detected in calves which can be responsible for zoonotic transmission of *cryptosporidiosis*.

Table 1. *Cryptosporidium* prevalence in various hosts by country of occurrence in Middle Eastern countries based on literature from the last one decade

Country	Sample Source (stool)	Investigation Method	Method and sequenced molecular markers	Study Period	<i>Cryptosporidium</i> spp.			<i>Cryptosporidium</i> spp.	<i>Cryptosporidium</i> spp. Subtype	Prevalence among species %	Age	Reference
					n positive	n total	% (CI)					
Iraq	Displaced Population	ELISA, modified ZiehlNeelsen, Flotation	--	2008-2014	780	780	--	<i>C. parvum</i>	--	16.28 25.45 30.3	— <1-5 6-12	Salman et al., 2015
Iran	Children (Hospitalized)	Ziehl-Neelsen	--	2014-2016	18	200	--	<i>C. sp.</i>	--	8 1	<4 >4	Dabirzadeh et al., 2017
	Children (Diarrhoea patients)	Ziehl-Neelsen staining,	PCR	2005-2007	19	794	--	<i>C. parvum</i> <i>C. hominis</i>	IIaA15G2R1 IIaA18G1 IIaA20G1a IIaA15G1 IfA22G1	89.47 10.52	--	Taghipour et al., 2011
	Farmworkers Calves	Ziehl-Neelsen , modified staining	PCR (18S rDNA)	2009-2010	31 36	218 422	--	<i>C. parvum</i>	--	Farmworker 8.5 9.6 8.3 Calves 14.2	-- <5 >5	Izadi et al., 2014
	Children	Acid-fast	PCR (18S	2015	2	113	--	<i>C. parvum</i>	--	1.7	3-12	Mahdavi

	(Diarrhoea patients)	staining, microscopy	rRNA, SSU rRNA)									Poor et al., 2015
	Children Immunosuppressed patients	Modified Zhiel-Neelsen, ELISA	--	2017	77 84	3630	54-83.9	<i>C. oocysts</i>	--	3.8 5.2	--	Kalantari et al., 2018
	Gastroenteritis Patients	Acid fast staining, Auramine phenol fluorescence	PCR-RFLP (SSU rRNA)	2010-2011	8	348	--	<i>C oocysts</i>	--	32.8 32.7 36.8	10-20 21-40 >40	Gholami et al., 2014
Kuwait	Children	ELISA	PCR-RFLP (SSU rRNA)	2005-2008	87	2548	--	<i>C. spp.</i> <i>C. parvum</i> <i>C. hominis</i>	IIa IIc IId Ia Id Ie	3.4 41.4 73.5 80.3 80.3 -- 26.5 36.4 54.5 --	-- 4-8 years	Iqbal et al., 2011
Lebanon	Children and Hospitalized patients	ZiehlNeelsen staining, microscopy	--	2017	16 25	163 249	--	<i>C. hominis</i> <i>C. parvum</i>	IdA19, IbA10G2, IaA18R3, IIaA15G1R1 ,	10.4 (Children) 11 (patients)	--	Osman et al., 2018

									IlaA15G2R1			
	Patients (colon adenocarcinoma)	Microscopy, immunofluorescence	PCR (18S rRNA)	2016	28	218	1.44- 89.02	<i>C. spp.</i>	--	21 (Cancer) 7 (No cancer)	--	Osman et al., 2017
	Hospitalized patients	Modified Ziehl- Neelsen staining, microscopy	PCR	2013	15	163	--	<i>C. spp.</i> <i>C. parvum</i> <i>C. hominis</i>	IdA19, IlaA15G1R1 , IlaA15G2R1	11 66.7 53.3	<5 year -- --	Osman et al., 2015
Saudi Arabia	Children (Diarrhoea and asymptomatic)	microscopy	--	2000	7	253	--	<i>C. sp.</i>	--	11 (Diarrhoea) 4.2 (asymptomatic)	<5 years	Al Braiken et al., 2004
Yemen	Children (Diarrhoea patient)	ELISA' modified Ziehl- Neelsen staining,	--	2006- 2007	247	712	--	<i>C. spp.</i>	--	20.2 48.1 43.1	1 month – 2 year 2 – 6 year 6 – 12 year	Al-Shamiri et al., 2010

A = Adult, **J** = Juvenile, **PCR** = Polymerase Chain reaction, **ELISA** = enzyme-linked immunosorbent assay

3.2 *Giardia lamblia* seroprevalence in Middle East

Giardia duodenalis (*G. intestinalis* and *G. lamblia*) are morphologically similar terms which are used interchangeably in this study. From *Giardia lamblia* species only *G. duodenalis* can cause infection among humans. Majority of the reports have identified *G. duodenalis* as cause of Diarrhoea in hosts. However, among the reported prevalence of *Giardia lamblia* subspecies *Assemblage/Genotype A.* and *Assemblage B.* among various segment of population and age groups. Other subspecies *Assemblage E.* and *Assemblage F.* are sparsely reported.

Giardia lamblia infections in Saudi Arabia were reported to be prevalent more in children under five years old (Shalaby et al., 2011). In Iran, prevalence of *Giardia lamblia* among children reported highest in children 4-6 years and lowest for children 0-2 years (Faraji et al., 2015). Also, in other study for diarrheic children; found *Assemblage B.*, B-IV and B-III predominant prevalence over *Assemblage A.* (El-Badry et al., 2018). *Assemblage B.* prevailed over *Assemblage A.* *G. lamblia* was prevalent in 1-10 years of age group in Iraq (Salman et al., 2015). The study in Lebanon reported, genotype *Assemblage B.* was predominant over *Assemblage A.* among school children (Osman et al., 2016). This may be due to Children infected with *Assemblage B.* released more cysts as compared to children infected with *Assemblage A.* (El Fatni et al., 2014).

The studies covering adult patients in Iraq, reported predominance of *Assemblage A.* over *Assemblage B.* Also study among food handlers depicted similar trend (Turki et al., 2015). The prevalence rate was affected by seasonal variation and was reported to be 25% for summer, 20% for spring, 15.15% for autumn and 0% in winter (Taha et al., 2018). Based on gender the prevalence in boys was higher than in girls (El Fatni et al., 2014). *Giardia lamblia* infections are more prevalent more in children under five years old and in elder population (Shalaby et al., 2011). Human transmission was indicated but the need for more investigations has been suggested to determine the dynamics of the real transmission and epidemiology (Hijawi et al., 2015). Adaptation of clean and hygienic practices was identifies as means to control transmission and morbidity attributed to *G. duodenalis* (Al-Mekhlafi, 2017).

Table 2. *Giardia lamblia* prevalence in Middle Eastern countries by country of occurrence for the last one decade

Country	Sample Source	Method (and sequence molecular markers)	Duration of study	N positive	N total	% (CI)	Genotype	Prevalence among species	Age	Reference
Iraq	Displaced Population (patients)	Microscopy	2014-2015	40	417	--	<i>G. lamblia</i>	10.31	--	Salman et al., 2016
	Children (Diarrhoeal)	PCR	2017	108	160	--	<i>G. lamblia</i> Genotype A Genotype B	26.25 28.57 71.43	--	Hussein et al., 2018
	Patients (acute or chronic Diarrhoea)	Flotation and PCR	2014-2015	73	200	--	Genotype A Genotype B Genotype E Genotype F	30.14 26.03 20.55 23.29	>1 - 40	Turki et al., 2015
	Children (<i>Giardia lamblia</i> infection)	ELISA	2016-2017	21	39	--	Genotype A Genotype B Mixed	23.80 71.42 4.76	0-11	Taha et al., 2018
	Children and Adults	microscopy	2015-2016	31	780	--	<i>G. lamblia</i>	3.9 7.3	1-20 >50	Bazzaz et al., 2017
	Children and Adults	microscopy	2011-2012	97	97	--	<i>G. lamblia</i>	25.77 22.68 22.68	1-10 11-20 21-30	Khudhair, 2020
Iran	Humans	microscopy	2015	222	4788	0.2-2.1	<i>G. lamblia</i>	3.8 9.4 4.9	<5 5-9 10-14	Siyadatpanah et al., 2018

								3.1	15-24	
								3.1	25-39	
								3.3	>40	
	Patients (<i>Giardia lamblia</i>)	PCR-RFLP	2010	174	205	--	<i>Assemblage AII</i> <i>Assemblage BII</i> <i>Assemblage BIV</i> Mixed A & B	74.41 17.44 3.49 4.66	--	Sarkari et al., 2012
	Food Handlers	Microscopy, PCR- RFLP	2015	47	3653	--	<i>G. lamblia</i>	74.5	--	Hooshyar et al., 2017
	Patients	Microscopy, PCR (TPI)	2015-2016	23	1383	--	<i>G. lamblia</i> <i>Assemblage A</i> <i>Assemblage B</i>	1.66 52 48	--	Bahrani et al., 2017
	Children (Childcare centre)	Microscopy	2012	134	632	--	<i>G. lamblia</i>	13.93 1.74 10.76 14.24	0-6 0-2 2-4 4-6	Faraji et al., 2015
Jordan	Patients	PCR (TPI)	2014-2015	49	49	--	<i>At tpi locus</i> A B Mixed A & B <i>At gdh locus</i> <i>Assemblage AII</i>	46.4 50 3.6 43.7	0>-45	Hijjawi et al., 2015

							Assemblage B	56.3		
Lebanon	School Children	Microscopy, Modified Ziehl- Neelsen staining, PCR	2013	61	212	--	<i>G. duodenalis</i>	28.5	3-16	Osman et al., 2016
Saudi Arabia	General Population (Healthcare facility)	PCR-RAPD	2010	15	100	--	<i>G. duodenalis</i>	15	--	Shalaby et al., 2011
Syria	Patients	microscopy	2006	206	1469	--	<i>Assemblage A</i> <i>Assemblage B</i> Mixed A +B	67.5 10 22.5	1-16	Skhal et al., 2016
Yemen	General Population (rural communities)	microscopy	2012-2014	170	605	0.73-1.48	<i>G. lamblia</i>	28.1 33.3 13.5	-- <5 >40	Al-Mekhlafi et al., 2017

3.3 Discussion regarding the transmission of *Cryptosporidium* and *Giardia lamblia* in Middle Eastern countries

A significant relation for based on gender, socio- economy in rural areas and animal contact role was derived (Shalaby & Shalaby, 2015). High affinity of infections was associated with tap water contamination and animal contact in urban populations (Gawad et al., 2018). There is a potential risk of zoonotic transmission of *Cryptosporidium* and *Giardia lamblia* to human beings (Ghoneim et al., 2017). Based on the zoonotic patterns of isolates, it can be identified that the mode of transmission is direct or indirect animal contact (Taghipour et al., 2011). Lebanon reported molecular analysis as an important tool to identify mode of transmission (Osman et al., 2016). Kuwait reported genetic condition of parasites plays important role in human cryptosporidiosis (Iqbal et al., 2011). Report from Jordan identified human to human transmission (Hijjawi et al., 2015). When there is no significant demographic variation then modes of transmission can be ingestion of contaminated water, and human or animal contacts (Iqbal et al., 2001). Identification of the transmission routes will help in adopting mitigation measures. Hence, prevent spread of the infection is the most effective strategy (Abd El Kader et al., 2012). However, zoonotic transmission cannot be eradicated from Middle Eastern countries as whole region practices animal husbandry owing to extreme conditions prevailing in most of the region rendering animals as sustainable source of food and other products thereof. Lack of awareness, personal hygiene and sanitation facilities, poverty, indiscriminate eating habits are favourable infestation conditions for *Cryptosporidium* and *Giardia lamblia* infections. The prevalence for both *Cryptosporidium* and *Giardia lamblia*, is higher in developing countries as compared to developed countries (Mahmoudi et al., 2017; Efstratiou et al., 2017). Interesting is the future study of statistics regarding the measures taken to prevent the disease in children and to treat the sick. However, there is very little information in open sources, which does not allow drawing logical conclusions about the better mitigation of the consequences.

4. Conclusions

The literature in this study was collected to present an overall scenario of prevalence of *Cryptosporidium* and *Giardia lamblia* in Middle Eastern countries. The study is in lieu with literature from other region however in details it varies globally and at local Middle Eastern countries level. The variance of *Cryptosporidium* and *Giardia lamblia* follows similar pattern in human and animals as reported worldwide. Poor sanitation and improper hygiene condition are primary responsible for occurrence and thereby transmission of the parasite. However zoonotic transmission arising from animal to human contact is also a significant factor. The

most affected section of population comprised of under 5 years of age children, patients (Immune deficient) and weaker economic section of population, moreover, the prevalence among boys was higher than among girls. This is as per the global trend of high prevalence in developing countries than in developed countries.

The major hurdle that the study faced was non uniformity of literature availability. The number of studies varied greatly which impacted the overall study efficiency. For example, Gulf countries viz. Saudi Arabia, Kuwait, Qatar, Bahrain, Oman, United Arab Emirates primarily depend on desalination as drinking water source which limits the need of protozoa occurring research and relevant mitigation measures. In addition, there is heterogeneity in testing procedures and standards across the Middle East, as well as a lack of standardized infrastructure. Hence these countries produced least number of relevant researches works. The other reason for low frequency of published report is the regional instability (political, socio-economical) faced in various countries viz. Syria, Yemen, Iraq, Palestine, Libya and affecting the neighbouring countries thereof (refugees) especially in last one decade which has highly compromised the scope of research in these countries.

Future research work should be based on existing literature on *Cryptosporidium* and *Giardia lamblia*. Additionally, future work can be specific to research on molecular techniques which can provide important information on various strains present in Middle Eastern countries. Also, for the future mitigation of the consequences, it is necessary to investigate the appropriate measures that were applied to prevent the disease in children (types of sanitation and hygiene, ways to increase immunity, dietary habits, environment, etc.) and for the treatment of patients (types and schedule of medicinal treatment, restrictions, etc.). The lack of public awareness recognizing *Cryptosporidium* and *Giardia lamblia* responsible for Diarrhoea in children needs to be addressed by relevant authorities.

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References

Abd El Kader N.M., Blanco M.A., Ali-Tammam M., Abd El Ghaffar A.E.R.B., Osman A., El Sheikh N., Rubio J.M. & De Fuentes I., 2012, Detection of *Cryptosporidium parvum*

- and *Cryptosporidium hominis* in human patients in Cairo, Egypt. *Parasitol. Res.* 110: 161–166. <https://doi.org/10.1007/s00436-011-2465-6>
- Al Braiken F.A., Amin A., Beeching N.J., Hommel M. & Hart C.A., 2004, Detection of *Cryptosporidium* amongst diarrhoeic and asymptomatic children in Jeddah, Saudi Arabia. *Ann. Trop. Med. Parasitol.* 97: 505–510. <https://doi.org/10.1179/000349803235002470>
- Ali M.A., Khamesipour A., Valian H.K. & Rahi A.A., 2014, Diarrhea caused by *Cryptosporidium parvum* in Kut, Iraq using different methods. 2: 1134–1138.
- Al-Mekhlafi H.M., 2017, *Giardia duodenalis* infection among rural communities in Yemen: A community-based assessment of the prevalence and associated risk factors. *Asian Pac. J. Trop. Med.* 10: 987–995. <https://doi.org/10.1016/j.apjtm.2017.09.011>
- Al-Shamiri A., Al-Zubairy A. & Al-Mamari R., 2010, The Prevalence of *Cryptosporidium* spp. in Children, Taiz District, Yemen., Iran. *J. Parasitol.* 5: 26–32.
- Bahrani F., Zamini G.H., Haghighi A. & Khademerfan M.B., 2017, Detection and molecular identification of human giardia isolates in the west of Iran. *Biomed. Res.* 28: 5687–5692.
- Bazzaz A.A., Shakir O.M. & Alabbasy R.H., 2017, Prevalence of two gastrointestinal parasites *Entamoeba histolytica* and *Giardia lamblia* within Samarra city, Iraq. *Advances in Bioscience and Biotechnology* 8(11): 399–410. <https://doi.org/10.4236/abb.2017.811029>
- Dabirzadeh M., Shahraki M.K., Rostami D. & Bagheri S., 2017, Prevalence of *Cryptosporidium* species in children referred to central and hospital laboratories of Zabol City, South East of Iran. *Int. J. Pediatr.* 5: 6359–6364. <https://doi.org/10.22038/ijp.2017.22358.1871>
- Dang T.D., Cochrane T.A. & Arias M.E., 2018, Future hydrological alterations in the Mekong Delta under the impact of water resources development, land subsidence and sea level rise. *Journal of Hydrology: Regional Studies.* 15: 119–133.
- Deineka, D., Kobziev O., Avina S., Grin S., Deyneka V., Taraduda D. & Sobina V., 2018, Studying the photocatalytic oxidation of hydroxybenzene in aquatic medium on the photocatalyzers SnO₂, ZnO, TiO₂. *Eastern-European Journal of Enterprise Technologies.* 5(6/95): 59–67. <https://doi.org/10.15587/1729-4061.2018.145198>
- Efstratiou A., Ongerth J., & Karanis P., 2017, Evolution of monitoring for *Giardia* and *Cryptosporidium* in water. *Water Res.* 123: 96–112. <https://doi.org/10.1016/j.watres.2017.06.042>
- El Fatni C., Olmo F., El Fatni H., Romero D. & Rosales M.J., 2014, First genotyping of *Giardia duodenalis* and prevalence of enteroparasites in children from Tetouan (Morocco). *Parasite.* 21: 48. <https://doi.org/10.1051/parasite/2014049>
- El-Badry A., Mohammed F. & Abdul Gawad E., 2018, Predominance of *Giardia intestinalis* assemblage B in diarrhoeic children in Sharkia, Egypt. *Parasitol. United J.* 10: 39–43. <https://doi.org/10.21608/puj.2017.4735>
- Faraji R., Ahmadian F., Javadi G. & Barshahi P., 2015, Prevalence of Giardiasis among children in childcare centers in Kermanshah, Iran. *Int. J. Res. Med. Sci.* 3: 1717–1720. <https://doi.org/10.18203/2320-6012.ijrms2015025>.
- Gawad S.S.A., Ismail M.A.M., Imam N.F.A., Eassa A.H.A. & Abu-Sarea E.Y., 2018, Detection of *Cryptosporidium* spp. in diarrheic immunocompetent patients in Beni-Suef, Egypt: Insight into epidemiology and diagnosis. *Korean J. Parasitol.* 56: 113–119. <https://doi.org/10.3347/kjp.2018.56.2.113>

- Ghenghesh K.S., Ghanghish K., BenDarif E.T., Shembesh K. & Franka E., 2016, Prevalence of *Entamoeba histolytica*, *Giardia lamblia*, and *Cryptosporidium* spp. in Libya: 2000-2015. *Libyan J. Med.* 11. <https://doi.org/10.3402/ljm.v11.32088>
- Gholami S., Khanmohammadi M., Ahmadpour E., Paqhe E.S., Nakhjiri S.K., Ramazannipour H. & Shahbazi A., 2014, *Cryptosporidium* infection in patients with gastroenteritis in Sari, Iran. *Iran. J. Parasitol.* 9: 226–232.
- Ghoneim N.H., Hassanain M.A., Hamza D.A., Shaapan R.M. & Draz S.H., 2017, Prevalence and Molecular Epidemiology of *Cryptosporidium* Infection in Calves and Hospitalized Children in Egypt. *Res. J. Parasitol.* 12: 19–26. <https://doi.org/10.3923/jp.2017.19.26>
- Hijjawi N., Yang R., Mukbel R., Yassin Y., Mharib T. & Ryan U., 2015, First genetic characterisation of *Giardia* in human isolates from Jordan. *Parasitol. Res.* 115: 3723–3729. <https://doi.org/10.1007/s00436-016-5132-0>
- Hooshyar H., Ghafarinasab S., Arbabi M., Delavari M. & Rasti S., 2017, Genetic variation of *Giardia lamblia* isolates from food-handlers in Kashan, Central Iran. *Iran. J. Parasitol.* 12: 83–89.
- Hussein A.A., Hussein R.A. & Shaker M.J., 2018, Enteric viruses co-infection with giardiasis among diarrheal children in Diyala Province-Iraq. *J. Pure Appl. Microbiol.* 12: 793–799. <https://doi.org/10.22207/JPaM.12.2.40>
- Iqbal J., Hira P.R., Al-Ali F. & Philip R., 2001, Cryptosporidiosis in Kuwaiti children: seasonality and endemicity. *Clinical microbiology and infection* 7(5): 261–266.
- Iqbal J., Khalid N. & Hira P.R., 2011, Cryptosporidiosis in Kuwaiti children: Association of clinical characteristics with *Cryptosporidium* species and subtypes. *J. Med. Microbiol.* 60: 647–652. <https://doi.org/10.1099/jmm.0.028001-0>
- Izadi M., Jonaidi-Jafari N., Saburi A., Eyni H., Rezaeiemanesh M.-R. & Ranjbar R., 2014, Cryptosporidiosis in Iranian Farm Workers and Their Household Members: A Hypothesis about Possible Zoonotic Transmission. *J. Trop. Med.* 2014: 1–7. <https://doi.org/10.1155/2014/405875>
- Kalantari N., Ghaffari S. & Bayani M., 2018, *Cryptosporidium* spp. infection in Iranian children and immunosuppressive patients: A systematic review and meta-analysis. *Casp. J. Intern. Med.* 9: 106–115. <https://doi.org/10.22088/cjim.9.2.106>
- Khan N.A., Khan S.U., Ahmed S., Farooqi I.H., Hussain A., Vambol S. & Vambol V., 2019a, Smart ways of hospital wastewater management, regulatory standards and conventional treatment techniques: a short review. *Smart and Sustainable Built Environment*. DOI: 10.1108/SASBE-06-2019-0079
- Khan N.A., Ahmed S., Vambol S., Vambol V. & Farooq I.H., 2019b, Field hospital wastewater treatment scenario. *Ecological Questions* 30(3): 57–69. <https://doi.org/10.12775/EQ.2019.022>
- Khudhair A.A., 2020, Prevalence of *Giardia lamblia* among Residents of Hawler, Soran and Chamchamal Cities, North of Iraq. *Pak-Euro Journal of Medical and Life Sciences* 3(2): 28–36.
- Liu J., Zhang Q., Singh V.P. & Shi P., 2017, Contribution of multiple climatic variables and human activities to streamflow changes across China. *Journal of Hydrology* 545: 145–162.
- Mahdavi Poor B., Rashedi J., Asgharzadeh M., Fallah E., Hatam-Nahavandi K. & Dalimi A., 2015, Molecular Characterization of *Cryptosporidium* Species in Children with Diarrhea in North West of Iran. *Int. J. Mol. Cell. Med.* 4: 235–239.

- Mahmoudi M.R., Ongerth J.E. & Karanis P., 2017, *Cryptosporidium* and *Cryptosporidiosis*: The Asian perspective. *Int. J. Hyg. Environ. Health.* 220: 1098–1109. <https://doi.org/10.1016/j.ijheh.2017.07.005>
- Mazzoni A. & Zaccagni S., 2019, Status of Water Resources and Human Health in the Middle East and North Africa Region: An Integrated Perspective, Reference Module in Earth Systems and Environmental Sciences. *Encyclopedia of Environmental Health* (Second Edition), p. 805-817. <https://doi.org/10.1016/b978-0-12-409548-9.11006-1>
- Michel D., Pandya A., Hasnain S.I., Sticklor R. & Panuganti S., 2012, Water Challenges and Cooperative Response in the Middle East and North Africa. *U.S.-Islamic World Forum*, p. 11–15. http://www.brookings.edu/~media/Research/Files/Papers/2012/11/iwf_papers/Water_web.pdf
- Osman M., Benamrouz S., Guyot K., Baydoun M., Frealle E., Chabe M., Gantois N., Delaire B., Goffard A., Aoun A., Jurdi N., Dabboussi F., Even G., Slomianny C., Gosset P., Hamze M., Creusy C., Viscogliosi E. & Certad G., 2017, High association of *Cryptosporidium* spp. infection with colon adenocarcinoma in Lebanese patients. *PLoS One.* 12: 1–10. <https://doi.org/10.1371/journal.pone.0189422>
- Osman M., Benamrouz S., Guyot K., El Safadi D., Mallat H., Dabboussi F., Hamze M., Viscogliosi E. & Certad G., 2018, Molecular epidemiology of *Cryptosporidium* spp. in North Lebanon. *J. Infect. Dev. Ctries.* 12: 34S. <https://doi.org/10.3855/jidc.10014>
- Osman M., El Safadi D., Benamrouz S., Guyot K., Dei-Cas E., Aliouat E.M., Creusy C., Mallat H., Hamze M., Dabboussi F., Viscogliosi E. & Certad G., 2015, Initial data on the molecular epidemiology of cryptosporidiosis in Lebanon. *PLoS One.* 10: 6–13. <https://doi.org/10.1371/journal.pone.0125129>
- Osman M., El Safadi D., Cian A., Benamrouz S., Nourrisson C., Poirier P., Pereira B., Razakandrainibe R., Pinon A., Lambert C., Wawrzyniak I., Dabboussi F., Delbac F., Favennec L., Hamze M., Viscogliosi E. & Certad G., 2016, Prevalence and Risk Factors for Intestinal Protozoan Infections with *Cryptosporidium*, *Giardia*, *Blastocystis* and *Dientamoeba* among Schoolchildren in Tripoli, Lebanon. *PLoS Negl. Trop. Dis.* 10. <https://doi.org/10.1371/journal.pntd.0004496>
- Salman Y.J., Aziz Al-Taee A.-R. & Abid A.M., 2016, Prevalence of *Giardia lamblia* among Iraqi Displaced Peoples in Kirkuk Province. *Int. J. Curr. Microbiol. Appl. Sci.* 5: 753–760. <https://doi.org/10.20546/ijcmas.2016.501.076>
- Salman Y.J., Sadek W.S. & Rasheed Z.K., 2015, Original Research Article Prevalence of *Cryptosporidium parvum* among Iraqi displaced people in Kirkuk city using direct microscopy. Flotation technique and ELISA-copro antigen test 4: 559–572.
- Sarkari B., Ashrafmansori A., Hatam G.R., Motazedian M.H., Asgari Q. & Mohammadpour I., 2012, Genotyping of *Giardia lamblia* isolates from human in southern Iran. *Trop Biomed.* 29(3): 366–71.
- Shalaby I., Gherbawy Y. & Banaja A., 2011, Molecular characterization of *Giardia* parasite isolated from stool samples collected from different hospitals in Taif City (Saudi Arabia). *Trop Biomed.* 28(3): 487–496.
- Shalaby N.M. & Shalaby N.M., 2015, *Cryptosporidium parvum* Infection among Egyptian School Children. *J. Egypt. Soc. Parasitol.* 45: 125–131. <https://doi.org/10.12816/0010858>
- Siyadatpanah A., Sharif M., Daryani A., Sarvi S., Kohansal M.H., Barzegari S., Pagheh A.S. & Gholami S., 2018, Spatial distribution of *Giardia lamblia* infection among general population in Mazandaran Province, north of Iran. *J. Parasit. Dis.* 42: 171–176. <https://doi.org/10.1007/s12639-018-0976-0>

- Skhal D., Aboualchamat G. & Al Nahhas S., 2016, *Giardia duodenalis* in Damascus, Syria: Identification of Giardia genotypes in a sample of human fecal isolates using polymerase chain reaction and restriction fragment length polymorphism analyzing method. *Acta Trop.* 154: 1–5. <https://doi.org/10.1016/j.actatropica.2015.10.008>
- Taghipour N., Nazemalhosseini-Mojarad E., Haghghi A., Rostami-Nejad M., Romani S., Keshavarz A., Alebouyeh M. & Zali M.R., 2011, Molecular epidemiology of cryptosporidiosis in Iranian children, Tehran, Iran. *Iran. J. Parasitol.* 6: 41–45.
- Taha S.A., Zein Abd Al Aal, Saleh N.S., & El-Badry A.A., 2018, *Giardia intestinalis* assemblages among Egyptian symptomatic children: Prevalence and seasonal distribution in Cairo, Egypt. *Journal of the Egyptian Society of Parasitology* 48(3): 661–668.
- Terink W., Immerzeel W.W. & Droogers P., 2013, Climate change projections of precipitation and reference evapotranspiration for the Middle East and Northern Africa until 2050. *Int. J. Climatol.* 33: 3055–3072. <https://doi.org/10.1002/joc.3650>
- Turki N.M., Mallah M.O. & Kremsh Y.D., 2015, Iraqi Genotyping of *Giardia lamblia* (A, B, E, F) in Human Stool In AL-Muthanna Province–Iraq. *International Journal* 3(10): 757–771.
- U.S.H.O.F., 2016, Representatives: I. Raad, G.P. Bodey, E. Health, The growing threat of cholera and other diseases in the middle east committee on foreign affairs subcommittee on Africa, global health. U.S. House of Representatives Health Outreach to the Middle East, President.
- WHO, 2019, Cholera Situation in Yemen, 22765604. http://www.emro.who.int/images/stories/csr/documents/Cholera_situation_update_Yemen_February_2019.pdf?ua=1
- Xu H. & May M.W., 2017, Water Availability Indices – A Literature Review. Argonne Natl. Lab. <https://doi.org/10.2172/1348938>
- Ziarati P., Kozub P., Vambol S., Vambol V., Khan N.A., Kozub S. & Tajik S., 2021, Kinetics of Cd, Co and Ni Adsorption from Wastewater using Red and Black Tea Leaf Blend as a Bio-adsorbent. *Ecological Questions* 32(2): 1–20. <http://dx.doi.org/10.12775/31823>