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Inconsistencies and Contradictions: Some Potential Effects of Groundwater Contamination on the Incidence of Diabetes Mellitus

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Abstract
Diabetes mellitus is one of the leading chronic and degenerative diseases in the world. It is caused by a myriad of established risk factors such as unhealthy diet, alcohol intake, tobacco use, and physical inactivity among others. Groundwater contamination, though not as prominent as the others, has surfaced as a possible predisposing risk factor of DM. Three major contaminants of groundwater, which have strong link to DM are arsenic, nitrate and fluoride. This paper reviews the findings of previous ecological studies on the nature of the relationship between DM and groundwater contaminants and highlights inconsistencies and contradictions in the findings. Therefore, it is too early to conclude on the effects of the groundwater contaminants on DM based on these early studies. It is still difficult to tell which DM type is more responsive to which groundwater contaminant. Finally, most of the existing studies have been carried out in Asia and Europe/North America regions while very little presently comes from Africa where there is very limited access to public water supply and most private water supplies depend on groundwater sources.

Keywords: *Diabetes, Groundwater, Geogenic, Arsenic, Safe water*

Introduction

Diabetes Mellitus (DM) is a non-communicable disease (NCD) characterised by high levels of blood sugar in the human body (WHO, 2016). It has also been defined as "… a group of metabolic diseases associated with hyperglycemia resulting from defects in insulin secretion, insulin action, or both." (American Diabetes Association, 2014:1). It is classified into two, namely, Type 1 DM and Type 2 DM. Type 1 DM is noted for deficient insulin production for blood sugar control while Type 2 DM is typified by the human body's ineffective utilization of insulin. Symptoms common to these two types are thirst, weight loss, hunger, excessive urination, poor eyesight and fatigue (WHO, 2016). The complications that arise from DM if not promptly managed are kidney failure, lower limb amputation, stroke, cardiovascular diseases among others (WHO, 2016). Like other NCDs, it has no single cause; it is caused by a variety of risk factors. As a matter of fact, Barker *et al*. (2011) explained that DM is the outcome of the interplay among behavioural, cultural, environmental factors genetic susceptibility This viewpoint obviously suggests that the disease is a product of a complex interaction among modifiable and non-modifiable risk factors as shown later in this discussion. Global figures on the number of people with DM are on the rise and show no immediate indication of decline. In 2000, there were151 million people in the world with DM which later increased to 425 million in 2017 (WHO, 2017). In 2019, 463 million adults between ages 20 and 79 had DM; the number has been projected to increase to 700 million by 2045. A little above 4 million deaths sadly have arisen from the disease (International Diabetes Federation, 2019). In terms of global distribution, nearly eighty percent (79%) live in low and medium income countries (LMICS) while 301.3 million people with DM live in urban settlements (International Diabetes Federation, 2019). Nearly 140 million persons with DM are above the age of 65. In addition, 1.1 million children and adolescents under the age of 20 have diagnosed Type 1 DM (International Diabetes Federation, 2019).

The rising disease burden has been attributed specifically to the increasing exposure of the human population to non-modifiable and modifiable risk factors such as family history of DM, unhealthy diets, overweight/obesity, physical inactivity and tobacco use (Villanueva *et al*., 2013; Osayomi, 2015, 2019; Forouhi and Wareham, 2019; Ghosh *et al*., 2019, Samuelsson *et al.,* 2019; Biradar and Singh, 2020; Wende *et al*., 2020). Although the existing literature has exhaustively pointed out the key contributions of non-modifiable and modifiable risk factors to the incidence, prevalence and geographical distribution of DM, the significance of groundwater contamination, is often overlooked or rather side-lined within the wider discourse on the aetiology of DM. Some authors have pointed out that the geographical distribution of DM in some parts of the world is partly accounted for by groundwater contamination (Lai *et al.,* 1994; Green et al. 2003; Schrober *et al*., 2003; Rytokonen, 2004). This of course suggests that groundwater contaminants have some role in the aetiology of DM. A better understanding of the links they share is crucial, not only, to medical geography, which often seeks to understand and account for geographic variations in disease occurrence, but also, to medical geology, whose fundamental concern is the effects of geological conditions on human health.

Ground water is vital to every society because it is a source of "…secure, sufficient and cost- effective water supply" (Tijani, 2016:52) and~~,~~ because of its numerous benefits to all spheres of life (Onianwa, 2016; Jahed *et al.,* 2019). This resource provides almost half of all the drinking water consumed worldwide; about 40 percent of water for irrigated agriculture and about one third of water supply required for industry (International Groundwater resources Assessment Centre [IGRAC], 2018). Estimates show that 4.2 million cubic kilometres of groundwater lies within the subsurface of the earth on which over 1.5 billion people depend for drinking (Tijani, 2016). In terms of its hydrochemical properties, it is said to be of good quality and therefore consumable (Shahid *et al*., 2018; Franscisco *et al*., 2019; Anim-Gyampo *et al*., 2019). However, this does not suggest that groundwater is always free of contamination (Tijani, 2016).

Given its properties, groundwater undergoes geogenic changes when it dissolves minerals present in rocks (Tijani, 2016). In addition, surface runoff, weathered products, composition of the underlying lithology alter the groundwater chemistry thereby affecting its quality (Olofinlade *et al*., 2018). In the process, the increased content of contaminants, which might include arsenic, cadmium, lead, mercury and fluoride has adverse effects on human health resulting in chronic kidney disease (Ahmed *et al*., 2016; Kafle *et al*., 2019) cancer, diabetes, hypertension (Anwar and Ran, 2013; Shukla and Saxena, 2018; Howard, 2019). Moreover, groundwater is suffering the ever-increasing pressure of anthropogenic activities, climatic change, and rapid urbanisation (IGRAC, 2018). This is against the backdrop of the increased dependence on groundwater resources stemming from high population growth and failed or at best limited public water supply in some resource-poor settings. On the whole, the effects of human-environment interactions on groundwater resources is likely to affect human health.

The following discussion presents an overview and assessment of contemporary research on the possible association between DM and groundwater contamination. Thus, the thrust of this paper is to vividly highlight areas of inconsistency and contradictions in existing studies in order to further research on the contributions of groundwater contaminants to the causation of DM with a view to effectively preventing and controlling DM. Therefore, the following questions were raised:+

1. What are the major contaminants of ground water in relation to DM?
2. What is the nature of the relationship between DM and groundwater contaminants?
3. Which type of DM is more responsive to which type of ground water contaminant?

Major Groundwater contaminants and their Connection with DM

The literature on DM has shown that, to some extent there are connections exist between the disease and groundwater contaminant, and has identified a few major contaminants which have significant diabetogenic effects. The contaminants are Arsenic (As), Nitrate (NO3-), and Fluoride (F). In the subsequent review, the effects of these contaminants on the aetiology of DM are highlighted.

Arsenic (As)

Arsenic (As) is a semi-metallic element from the earth's crust, which is very poisonous in its inorganic state and in varying concentrations (Ahmed *et al.,* 2017; Asher *et al*., 2017; Lucio *et al.,* 2020). The presence of As in groundwater is the result of the dissolution of minerals from rock and soil weathering (Showstack, 2000, Reynolds, 2008; Hamidian et al 2019). Besides the weathering effect, its presence in groundwater is also dependent on climate, and hydrochemical characteristics (Hamidian *et al*., 2019). Exposure to As is often through drinking contaminated water and eating food prepared, or crops irrigated with contaminated water. It also occurs through consumption of As contaminated sea foods (Reynolds, 2008; Makris *et al.,* 2012; WHO, 2016; Chakraboti *et al*., 2017).

For many years, the occurrence of high As concentration in drinking water has grown to become a major public health concern around the globe (Mukherjee *et al*., 2000). Concentrations are present in numerous countries such as the USA, Bangladesh, Chile, Mexico, India, Argentina and China (WHO, 2016). Bangladesh has been a focus of several arsenic studies due to high concentrations in its groundwater supplies (Reynolds, 2008; Yunus *et al.,* 2011; Nesha *et al.,* 2018; Naser *et al.,* 2019; Paul *et al*., 2019). For example, As contamination in the Ganges Delta region of Bangladesh and West Bengal, according to Rahman *et al*., (2009), has been labelled as the greatest environmental health crisis because over 100 million people there are susceptible to As poisoning.

Groundwater contamination with As is a major cause of skin lesions; darkening of the skin; cardiovascular diseases; lung, skin, and bladder cancers; and methaemoglobin (better known as the Blue Baby syndrome) among others (Mukherjee *et al.,* 2000; Knobeloch *et al.,* 2000, Hamidian *et al.,* 2019). The likelihood of being diagnosed with any of these ailments is largely dependent on the dose and duration of exposure to As (Mukherjee *et al.,* 2000).

Ingestion of chronic levels of arsenic in drinking water is perceived to be the reason for an increased risk of type 2 DM. (Mukherjee *et al.,* 2000, Tseng *et al.,* 2000; Nesha *et al.,* 2018). According to Makris *et al.,* (2012), As exposures provoke cellular reactions associated with stimulating insulin secretion, eventually affecting B cell function. Accumulation of arsenic in the pancreas inhibits insulin production, thereby making cells less viable. In Hassan *et al* (2017)'s synthesis of the literature, the administration of As in experimental animals affected insulin receptors and glucose transportation (Tseng *et al.,* 2000); and increased resistance to insulin, leading to hyperglycaemia and eventually DM (Hassan *et al.,* 2017). Therefore, As plays a biological role as a diabetogenic risk factor (Jovanic *et al.,* 2013; Grau-Perez *et al.,* 2018)

However, findings from a number of studies which have examined the relationship between As and DM are conflicting. On one hand, some studies have recognised positive associations between high As concentration in groundwater and DM. For instance, Makris *et al* (2012) assessed the degree of association between orally ingested As and self-reported DM in a specific area of Cyprus. A potential explanation for the occurrence was drinking water with high As (Makris *et al.,* 2012). In Newfoundland and Labrador, Canada, significant association between higher concentration of As and higher DM at the community level was observed whereas no relationship was detected at the regional level (Chafe *et al.,* 2018). In areas of Iran where the presence of arsenic in water, soils and thermal springs was attributed to recent vulcanism and its subsequent hydrothermal activities, people with chronic exposure to As showed DM and hypertension. (Modabberi *et al.,* 2015)

Grau-Perez *et al* (2018) reported that arsenic ingestion was directly correlated with the incidence of type 2 DM in Spain. The reason was because of the heavy consumption of arsenic contaminated sea food among its people. Similarly, arsenic contamination was positively related to type 2 DM among American Indians because they lived where there were moderately high levels of inorganic arsenic and ate As contaminated sea food (Kim *et al.,* 2013). In Pakistan, Idrees and Batool (2013) observed increased risk of DM in people who consumed chronic As contaminated water. Makran *et al* (2013) found a positive correlation between As and DM and hypertension in the urban region of Qazvin, Iran. This positive association is again supported by Lampron-Goulet *et al* (2017)'s study of groundwater contamination in rural Quebec, Canada. A positive correlation was observed between As and Type 2 DM among Croatians (Lucio *et al.,* 2020). Nesha *et al* (2018) reported that prolonged exposure to As in drinking water caused type 2 DM. Low or moderate amounts of As exposed persons to greater risk of DM in Bangladesh (Paul *et al.,* 2020). In nearby Pakistan, significant association was found between type 2 DM and chronic As contaminated water (Idress and Batool, 2018). In the Middle Banat region of Serbia, a cross sectional study showed that population from Middle Banat region exposed to low levels of arsenic in drinking water was at higher risk for the occurrence of type 2 DM than others (Jovanic *et al.,* 2013)

On the other hand, there is some evidence of no association between As and DM. A study conducted in Saskatchewan, Canada revealed contradictory findings. In one case, no evidence found of an association between groundwater from public supplies and private wells and increased incidence of DM. In another case, a significant but non-linear relationship between high As and decreasing DM was detected. In other words, no direct relationship was recorded (McLeod *et al.,* 2019). Lai *et al* (2013) found no association between exposure and DM in an arsenic contaminated area of inner Mongolia; but high level arsenic exposure contributed to a higher risk of hypertension only. Similarly, no association between environmental arsenic exposure and type 2 DM was found in Thailand (Sripaoraya *et al.,* 2017) and in China (Zhang *et al.,* 2020).

In some unique circumstances, the interaction between As and DM had different pathways. For instance, As exposure was indirectly linked to DM via the cultivation and consumption of rice in arsenic-contaminated regions. It is thought that the cultivation and cooking of rice with contaminated underground water increases the ingestion of As which in turn affects the pancreatic cells (Hassan *et al.,* 2017). Another interesting example was in northern Chile where Castriota *et al* (2018) found that type 2 DM risk was high in obese persons when exposed to As. As might worsen or increase the risk of obesity related type 2 DM. This result suggested a synergistic relationship between obesity and As. Just as Chakrabati *et al* (2018) rightly observed in their assessment, there are mixed results on the association between As and DM.

Nitrate (NO_3-)

Nitrate (NO_3- NO_3-) is one of the globally recognised groundwater and surface water contaminants on earth (Shukla and Saxena, 2018; Azhdarpoor *et al.,* 2019). Nitrate contaminates groundwater in a number of ways including fertiliser application, human and animal waste, explosives, deforestation, geology and lightning storms (Shukla and Saxena, 2018). As it is well known, nitrogen is one of the most important nutrient plants need to grow. Inorganic N fertilisers were introduced to boost food production in relation to the growing global population (Ahmed *et al.,* 2017). Nitrate concentrations have dramatically increased in the world due to the increasing use of inorganic fertilizers and animal manure (Ward *et al.,* 2018, Soraya *et al.,* 2016; Yang and Liu, 2010, Ahada and Suthar, 2018; Shukla and Saxena, 2018). Nitrates, which are the final products of N fertilisers, if not absorbed directly by plant roots, are leached down to groundwater (Ahmed *et al.,* 2017). The excessive use of nitrate-based fertilisers has had its adverse effects on the environment and human health (Ahmed *et al.,* 2017, Shamusuddin *et al.,* 2016). Populations with the highest NO_3- concentrations in their drinking water are those in agrarian regions whose drinking water sources are close to nitrogen sources (Ward *et al.,* 2018). The consumption of diets with high nitrate content contributes to DM, cancer and thyroid condition (Ahmed *et al.,* 2017).

Like As, high concentrations of NO_3- cause the Blue Baby Syndrome, where "… it binds with the red blood cells and reduces their ability to carry oxygen, this leads to shortness of breath, heart attack and even death" (Soraya *et al.,* 2016:809). NO_3- concentration affects oxygen flow in the blood causing the Blue Baby Syndrome (Yang and Liu, 2010). With respect to DM, Kostraba *et al* (1992) theorised that ingestion of NO_3- damages insulin producing cells in the pancreas through the generation of free radicals.

Like As, there are conflicting findings on the association between DM and NO_3-. Some ecological studies have demonstrated a positive association. For instance, Parslow *et al* (1997) examined the relationship between the incidence of childhood DM and the level of NO_3- in drinking water in Yorkshire, northern England and found a positive association. Also, Longnecker and Daniels (2001) in their review of the literature observed the contribution of NO_3- to the increased risk of type 1 DM.

On the other hand, other studies indicated a negative or no association. In Sardinia, Italy, Type 1 DM did not increase with NO_3- concentration in community water supplies but instead there was a significantly inverse relationship (Muntoni *et al.,* 2006). Benson *et al* (2010) examined the relationship between NO_3- concentration in food and drinking water and type 1 DM risk in Canada and arrived at the conclusion that NO_3- was not related to type 1 DM. Shamusuddin *et al* (2016) saw no significant association between nitrate and DM in Kelantan. Findings from Sardinia (Casu *et al.,* 2000) and Netherlands (van Maanen *et al.,* 1999) confirm this inverse association with type 1 DM.

Fluoride (F)

Low concentration of Fluoride (F^-) is essential for dental protection and beneficial for human health (Azhdarpoor *et al.,* 2019). It reduces the prevalence of dental caries. However, it causes tooth and skeletal fluorosis following prolonged intake (WHO, 2010; 2019). Excessive fluoride intake occurs via any of the following channels: consumption of fluoride-rich groundwater or crops that take up fluoride from irrigation water sources (WHO, 2010).

F^- contamination is accountable for 65 percent of endemic fluorosis in the world (Azhdarpoor *et al.,* 2019). This is confirmed by Narsimha and Rajitha (2018)'s study in Telangana State of South India. Sources of groundwater contamination with F^- include volcanic emission; rock weathering and dissolution into groundwater; production of phosphate fertilisers; manufacture and use of hydrofluoric acid; and burning of fluoride-rich coal (WHO, 2010).

The literature is replete with studies on health effects of F^- contamination of groundwater (Dissanayake and Chandrajith, 2017; Adimalla, *et al.,* 2018; Adimalla and Wu 2019, Karunanidhi *et al.,* 2019; Li *et al.,* 2019). However, the literature on F^- contamination and DM is currently very scanty. Chafe *et al* (2018), identified a positive correlation between fluoride, along with other other contaminants, and DM in communities in Saskatchewan, Canada. There is still a lot to be explored about this relationship.

Conclusion

Based on the scanty literature, this paper has presented a summary of the associations between DM and three major identified groundwater contaminants; and reviewed the nature of their relationship with DM; and identified the groundwater triggers for type 1 and 2 DM. Some key conclusions have emerged from the review. Firstly, there are inconsistencies and contradictions in the findings reported on the subject matter. Therefore, effects of contaminants on DM are still inconclusive. These inconsistencies or contradictions could be tied to any or a combination of the following factors: cultural, dietary, or technological features among others. Secondly, it is difficult to tell which DM type is more responsive to which groundwater contaminant given the inconsistences in results as earlier stated. Despite these observations, it appears that type 2 DM is triggered more by arsenic and nitrate. However, this still needs to be empirically verified. Thirdly, it seems that a significant amount of research has generally been done in Europe/North America and Asia on this research theme while very little presently comes from Africa where there is limited access to public water supply, and where private water supply largely depends on groundwater resources. This is certainly a potential avenue of inquiry. The association between groundwater contamination and DM in Africa has not yet been studied and needs to be given scholarly attention in African countries. Lastly, the relative contribution of ground water contamination in the DM causation process cannot be dismissed; but at the same time, it cannot be conclusively recognised as a principal factor in the web of causation, given the multiplicity of causal factors in DM.

DM prevention and control programs for some time have been overly emphatic on medications and lifestyle change but little or no attention is paid to environmental factors such as groundwater contamination. In conclusion, this review paper calls for more scientific studies to further probe this association especially in regions of the world where it has not yet been reported. There is also a need to assess the geographical prevalence of DM in relation to sources of groundwater contamination. Hopefully, this review and future investigations that might follow would provide direction for human health risk assessment and health education ultimately for the successful prevention and control of DM.

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