Musned H I. 2000, the role of wind barriers in desert land reclamation, the experience of Karma Basin, working meeting water resources and development Northern State (In Arabic).
Omer S M, Thompson J L C.1970. Survival of female Anopheles gambiae Giles through a 9 month dry season in Sudan. Bulletin of World Health Organization, 42(2),319.
Osei F B, Yibile M M.2015. Geographic Patterns of Malaria in the Brong Ahafo Region of Ghana. Austin journal of public epidemiology 2 (2): 1022.
Prothero R M. 1961. Population movements and problems of malaria eradication in Africa. Bulletin of World Health Organization, 24:405-25.
Prothero R M. 1965. Migrants and Malaria. London. Longman.
Prothero R M. 1994. Malaria in the nineties. Geography, 80: 411-14.
Prothero R M. 2001. Malria and the importance of people. Development in practice, 111:86-91.
Simon I H, Carlos A G, et al.2004. The global distribution and population at risk of malaria: past, present, and future. The Lancet infectious diseases 4 (6):327-336.
Singhanetr R A. 1993. Malaria and mobility in Thailand. Social Sciences and Medicine, 37:1147-54.
Sudapedia. climate of Sudan. Sudapedia.sd/ar/content/136,
Tawanda M, Moses J. Chimbari, M, et al. 2004. A review of the emergence of Plasmodium falciparum dominated malaria in irrigated areas of the Thar Desert, India. Acta Tropica, 89(2):227-239.
Tyagi B K, Yadav S P. 2001. Bionomics of malaria vectors in two physiographically different areas of the epidemic-prone Thar Desert, north-western Rajasthan, India. Journal of arid environments 47,(2):161-172.
Ubydul H, Toshihiko S, Masahiro H, Timothy S, Taro Yamamoto, et al.2009. Malaria Prevalence, Risk Factors and Spatial Distribution in a Hilly Forest Area of Bangladesh. PLoS One 4 (8):e6737.
US-Sudan Business Council. 2018. Special Report Sudan. A dynamic private sector open to the world, published in cooperation with the US-Sudan Business Council,.
Wilson M D, Boakye D A, Okoya P N, Brown C A.2005. Impact of the Okyereko irrigation project in Ghana on the risk of human malaria infection by Anopheles species (Dipetra: Culicide). African Entomology, 13(2):249-253.
World Health Organization. 2015. World Malaria Report. Geneva.
World Health Organization. 2016. Malaria fact sheet. Geneva.
Yang D, Xu C, Wang J, Zhao Y.2017.Spatiotemporal epidemic characteristics and risk factor analysis of malaria in Yunnan Province, China. BMC public health 17 (1),66.
Yongze S, Yong G, Jinfeng W, Zhoupeng R, Yilan L, Junhuan P.2016. Spatial distribution estimation of malaria in northern China and its scenarios in 2020, 2030, 2040 and 2050. Malaria journal 15 (1), 345.
Zhuoma Y J, Wu X L, Wang H JU. 2012. Analysis of malaria epidemic in Motou county, Tibet in 1981-2010. China tropical medicine, 3.

entomology, 15(1):1-11.
Ijumba J N, Shenton F C , Clarke S E , Mosha F W, Lindsay S W. 2002. Irrigated crop production is associated with less malaria than traditional agricultural practices in Tanzania. Transactions of the Royal Society of Tropical Medicine and Hygiene, 96(5)476-480.
Jayaraman T K. 1982. Malarial impact of surface irrigation projects: S case study from Gujarat, India. Agriculture and environment, 7(1):23-34.
Jhajharia D, Chattopadhyay S, et al. 2013. Influence of climate on incidence of malaria in the Thar Deser, northweste India. International journal of climatology, 33(2): 312-325.
Keiser J, Caldas M, Maltese M F, Boss R. 2005. Effect of irrogation and large dams on the burden of malaria on a global and regional scale. The American journal of tropical medicine and hygiene, 72(4):392-406.
Khartoum State Ministry of Health, 1996. Malaria records files. Khartoum Sudan.
Kibert S, Alemu Y, Boelee E, Tekie H, Alemu D .2010. The impact of a small scale irrigation scheme on malaria transmission in Ziway area, central Ethiopia, Tropical medicine and international health, 15(1):41- 50.
Kopec E G, Kawano M, et al. 2005. An online operational rainfall-monitoring resourcefor epidemic malaria early warning systems in Africa. Malaria Journal 4, (1),6.
Leah R, Johnson K D, et al. 2010. Mapping the distribution of malaria: current approaches and future directions". Edited by: Dongmei C, Bernard M, and Jianhong W. https://doi.org/10.1002/9781118630013.ch10
Lehmann T, Dao A, et al. 2010. Aestivation of the African malaria mosquito, Anopheles gambiae in the Sahel. The American journal of tropical medicine and hygiene, 83(3):601-606.
Lysenko A J, Beljaev A E. 1969. An analysis of the geographical distribution of Plasmodium ovale. Bull World Health Organ, 40:383–94.
Lysenko A.J. and Semashko I.N. 1968. "Geography of malaria. A medico-geographic profile of an ancient disease" In: Lebedew AW, (editor): Itogi Nauki: Medicinskaja Geografija. Academy of Sciences, USSR; Moscow: 1968. pp. 25–146.
Malcolm C A, Welsby D A, ElSayed B B. 2007. "SIT for the malaria vector anopheles arabiensis in Northern State, Sudan: an historical review of the field site" In: Vreysen M J B, Robinson S A , Henddrich J (eds) Area wide-control of insect pests. Springer, Dordrecht.
Malik E M, Khalifa O. 2004, Malaria in Sudan: past,present and the future. Gezira journal of health sciences, 1(1)
May J M. 1958. The ecology of human diseases.New York: M.D.Publications.
Meade M S. 1976. Land development and human health in West Malasia. Annals of Association of American Geographers, 66: 428-39.
Metselaar D, Van T P H. 1959. Classification of malaria. Trop Geogr Med.,11:157–61.33.
Ministry of Health 1995. Statistical Yearbook. Ministry of Health.Khartoum
Ministry of Finance and Economic Planning .2008. Population Census 2008.
Ministry of Finance and Economic Planning, Sudan. 2008. Sudan census. Ministry of Finance and Economic Planning, Sudan.
Ministry of Finance, Northern State, Sudan. 2003. 25, Agriculture (In Arabic).

Baeza A Bouma, M J Dobson A P, et al. 2011. Climate change and desert malaria: the effect of irrigation. Malaria journal, 10 (1):190.
Carter R, Mendis K N. 2002. Evolutionary and historical aspects of the burden of malaria. Clinical Microbiology Review, 15:564–94.
Craig M H. 2009. The temporal and spatial distribution of malaria in Africa, with emphasis on Southern Africa. Doctoral Thesis, University of Basel, Faculty of Science.
Dams Implementation Unit.2019. Merowe Dam. diu.gov.sd
Davies H R J. 1991. "Population change in the Capital Region" in Abu Sin & Davies (eds), The future of the Capital of Sudan, Khartoum University Press.132-141.
Dukeen M Y H and Omer S M. 1986. Ecology of the malaria vector Anopheles arabiensis patton (Dipetra: Culicidae) by the Nile in Northern Sudan. Bulletin of entomology research, 76(3):451-467.
Dutt H M and Dutt A K. 1978. Malarial ecology: A global perspective. Social Sciences and Medicine, 12:69-84.
Elhassan A A.1998. The medical geography of the Gezira scheme. Unpub. M.A. Thesis, University of Khartoum.
El-Sayed B B, Arnot D E, Mukhtar M M, Baraka O Z, et al. 2000. A study of the urban malaria transmission problem in Khartoum. Acta Tropica, 75:183-71.
Fábio S, Monteiro D B, Nildimar A, Honório M, Eliane A. 2011.Temporal and spatial distribution of malaria within an agricultural settlement of the Brazilian Amazon. https://doi.org/10.1111/j.1948-7134.2011.00153.x:
Farid M.1977. Irrigation and malaria in arid lands. Arid land irrigation in developing countries, 413-419
Federal Ministry of Health, Sudan. 2017. Annual Health Statistical Reports, 2007-2017, National Centre for Health Information. NCHI.Gov. Sd.
Fuller D O, Pareenti, M S, et al. 2012. Linking land cover and species distribution models to project potential ranges of malaria vector: an example using A. Arabiensis in Sudan and Egypt. Malaria journal, 11, 264 doi:10.1186/1475-2875-11-264.
Giha H A, Rosthoj S, Dodoo, D. 2000.The epidemiology of febrile malaria episodes in an area of unstable and seasonal transmission. Transactions of the Royal Society of tropical medicine and hygiene, 94(6):645-651.
HAG A. 1991. "Rural Khartoum development systems: patterns, trends and prospects" in Abu Sin & Davies (eds), The future of the Capital of Sudan, Khartoum University Press.1991, 86-97.
Hamad G M. 2002. Local level authorities and local action in Greater Khartoum. The Arab World Geographer, 3:238-48.
Hassan M, Khormiand L K. 2016. Future Malaria Spatial Pattern Based on the Potential Global Warming Impact in South and Southeast Asia. https://www.geospatialhealth.net/index.php/gh/article/view/416/506
Himeidan Y E, Bashir S, ElRayah M I, Adam A I .2005. Epidemiology of malaria in New Halfa, an irrigated area in eastern Sudan. EMHJ-Eastern Mediterranean Health Journal, 11 (3): 499-504.
Himeiden Y E, Elzaki M M, et al. 2011, Patterns of malaria transmission along the Rahad River basin, Eastern Sudan. Parasites and Vectors, 4,109-doi:10.1186/1756-3305-4-109.
Ijumba J N .2001.Impact of irrigation on malaria in Africa: paddies paradox. Medical and veterinary

where surface waters required for larval development are absent for 4-8 months per year and under such conditions Anopheles gambiae disappears. It furthermore agrees with the fact that, whether Anopheles gambiae populations survive the long dry season by aestivation or are re-established by migrants from distant locations where larval sites persist has remained an enigma for over 60 years this is important because fragile dry season populations may be more susceptible to control (Lehmann et al., 2010). The model integrated commensurate development of preventive infrastructure, public hygiene and reasonable housing with vast increase in agricultural expansion. Such vast increase is needed_because achievement of food security for the rapid growing population of Sudan and the need for provisioning of jobs opportunities for the growing working youth are vital. The model also, considered environmental health policies and plans and community awareness on malaria prevention and fighting have to be integral part of agricultural development programs. This is very important as community participation in environmental management became beneficial in recent times. The model also considered that the impact of epidemic in general could be controlled or minimized by prediction and improved prevention through timely vector control and deployment of appropriate drugs. This could be more enhanced by malaria Early Warning Systems as a means of improving the opportunity for preparedness and timely response (Kopec et al., 2005). In addition, changing of traditional cropping system might help curbing malaria in arid Sudan since there is a concern that crop irrigation that results in increased numbers of vector mosquitoes will lead to a rise in malaria in local communities (Ijumba et al., 2002), and the experience of rice irrigation was associated with less malaria than alternative agricultural practices, despite the considerable numbers of vectors produced in paddies. As the majority of the agricultural development is in arid Sudan is privately owned farms, particularly the Arabs, their incorporation into the achievement of the integrated parts of the proposed model is vital.

This proposed model here, if successfully implemented could be transferred to other areas of Sudan and to other similar environments worldwide.

REFERNCES

Abdisalan M N, ElMardi, K A, et al. 2012. Malaria risk mapping for control in the Republic of Sudan. The American journal of Tropucal Medicine and Hygiene, 87 (6):10120-1021.

Aboud M, Makhawi A, Verardi A, et al. 2014. A genotypically distinct, melanic variant of A. Arabiensis in Sudan as associated with arid environment. Malarial journal, 13 (1):492, doi:10.1186/1475-2875-13-497.

Abuzeid H A, Hamid A A, and Mustafa M A .2017. Assessment of wind erosion in central part of the Northern State, Sudan. Sudan Journal of Desertification Research, 9(1):29-37.

Ahmed A, and Yassin F, et al. 1981. The Democratic Republic of Sudan, Ministry of Energy and Mining, geological and mineral resources department. Bulletin n° 35 explanatory note to the geological map at scale of 1:2 000000. Edition SD - 84, 02 1984.

Ail R A. and Elshayeb A A .2011. The effects of climate changes on the distribution and spread of malaria in Sudan. American journal of environmental engineering, 1, 1520.

Akhtar R, Learmonth M k.1977. The resurgence of malaria in India 1965-76. Geojournal 1 (5):69-76.

Alredaisy S M A and Davies H R J . 2003. The ecology of malaria in urban squatters of Greater Khartoum, Gamier area in Omdurman. Arab World Geographer, 6(3): 178-193.

associated with agricultural development might help also in the spread of malaria in the two States since forest coverage has proved to be a significant risk factor for malaria infection in a hilly forest area of Bangladesh (Ubydul et al.,2009).

The huge water reservoir created by Merowe Dam is expected to increase malaria incidence in such arid environment of the Northern State, and is expected to be more influential by the completion of the proposed Dams. These dams could hamper river flow and water level variation; acting as reservoirs of larvae; produce year-round breeding sites; suggests for changes in the ecosystem in an endemic malaria area; may influence mosquito reproduction patterns; and produce changes in malaria seasonality (Fábio et al., 2011). Dams in Brazilian Amazon were the only positive breeding sites during the wet season as no larvae were found in the river and larval collections from all sites in the river bed were positive for An. darlingi immature stages in the dry season where the riverbed formed puddles, which were readily colonized by mosquito larvae of various species (Fábio, 2011).

Agricultural expansions in Northern and River Nile States will attract labour force mostly, from central and western Sudan which are mesoendemic areas of malaria endemicity. This will significantly influence both States since the importance of migration in the spread of various diseases in tropical Africa has been well documented (Alredaisy and Davies, 2003), and various facets of the effects of migration on the spread and incidence of malaria have been examined seriously since the 1950s (e.g., May, 1958; Prothero, 1961; 1965; 1994; 2001; Meade, 1976; Singhanetra, 1993). The tradition movement of east-wards by western Sudanese and West Africans along the savannah grass road and nomadic migration with the seasons are very significant in the spread of malaria in Sudan. This has been confirmed in the Gezira scheme where the long –standing contention among the Gezira tenants and these migrants were an important factor in this disease (Elhassan, 1998). That was due to agricultural extension into the fertile lands of Sudan following the establishment of Geizra Agricultural Scheme in 1924.

Agricultural expansion and building of dams in Northern and River Nile states are expected to change malaria endemicity from Hypoendemic to Mesoendemic. This will make both States and central Sudan a one continuous geographic area of mesoendemic malaria, and might extend to include Mediterranean land. This will result in one continuous mesoendemic zone of malaria extending from interior Africa up to the Mediterranean. According to Simon et al. (no date) preliminary analyses of existing endemicity maps indicate the probable extent of malaria infection risk outside the AFRO area, and particularly in the SEARO region, conclusions that remain strong even under very optimistic scenarios of endemicity reduction.

Towards a model for control of malaria in arid Sudan

The proposed model (Figure 5) consists of six working integral parts to achieve its proposed purposes. Complementary programs of eradication of malaria in central Sudan have to be integrated with those in the new agricultural openings. The old experience of malaria control in central Sudan was evident where Khartoum town itself was declared free of malaria from 1904 during the Anglo-Egyptian Condominium (Gleichen, 1905). Environmental policies and plans which commensurate with "the extent of the malaria problem connected with irrigation in arid zones does not depend as much on the climatic conditions or the potentiality of the vector in establishing malaria transmission as on man-made disturbance of the ecologic balance" (Farid, 1977) were integrated in the model. This integral parts agrees also with that, Anopheles gambiae, inhibits diverse environments including dry savannas, perennial and moderate rather than low (Himeidan et al., 2005). This demarcates seasonality in malaria transmission where Giha et al., (2000) confirmed seasonality in transmission and the epidemiology of uncomplicated falciparum malaria in eastern Sudan. They found that about 90% of malaria morbidity occurs during dry months and years of drought (Giha et al., 2000).

In the semi desert habitat of western Khartoum State adult population of A. Arabiensis survive through the long dry season in a state of partial aestivation, characterized by limited feeding activity and a degree of arrested ovarian development (Aboud et al., 2014). This accord with the study by Omer et al. (1970) who found that in the valley of the White Nile the species maintained itself by low-level breeding through the dry months

Relevant research in Africa and Asia provides supporting evidences for the fore discussion. The study by Kibert et al. (2010) in two villages in a semi arid area of Ethiopia found that, malaria prevalence was higher in an irrigated village than in the non-irrigated one. It is even higher during the dry season in the irrigated village than the wet season compared to the non-irrigated village. Generally, irrigation schemes among the Ethiopian Rift Valley may intensify malaria by increasing the level of prevalence during the dry season (Kibert et al., 2010). In coastal savannah of Ghana, Okyereko irrigation project provided evidence that malaria risk was lower at the irrigated village compared to non irrigated village during the dry season and the likely reason is the low numbers of An. Funestus and An. Gambiae s.s. form (Wilson et al., 2005). In India, year- round irrigation and multiple cropping have given rise to an increase in the incidence of malaria over an 18-year period in the Mahi-kadana irrigation Project in Gujarat State, India. Further man-made disturbances such as over-irrigation and lack of drainage have also compounded the problem (Jayaraman, 1982). Thar Desert in India is currently suffering from the impact of repeated annual epidemics due to progress of canal-irrigation work where malaria prevalence rate was higher in an irrigated village compared to a truly desertic unirrigated village (Tyagi, 2001). P. falciparum malaria incidence cases have been found to increase significantly corresponding to dry months and seasonal monsoon time scales over Bikaner in Thar Desert (Jhajharia et al., 2013). “Therefore, the Thar Desert provides an excellent model for understanding the underlying factors responsible for the exacerbation of evolution of the epidemics” (Tyagi, 2004). In border counties in south-western China and especially in Yunnan Province which is semi arid, malaria cis a serious health problem (Yang et al., 2017), and in Motou County malaria increases during summer and distributed in townships along Yaluzangby River in Mengba national minority (Zhuoma et al., 2012).

Micro-climatic changes are expected in Northern and River Nile States due to recent agricultural expansion and building of new dams. This has been confirmed by that, change in the distribution of malaria is foreseeable because of potential consequences of anthropogenic climate change as was evident in southern and south-eastern Asia (Hassan, et al., 2016). Since malaria is known to be sensitive to climate factors it could consequently develop for several months in most areas of Sudan (Aal and Elshayeb, 2011), including both States although they have maximum average temperature above 37^0 C and minimum average temperature below 10 C ^{0}, which are not so conductive to the malaria mosquito's survival (Akhtar et al. 1977). It also expected that introduction of animal keeping and forests plantation into these new agricultural expansions will contribute in malaria transmission and endemicity. This supported by that, agricultural settlements, as well as small-scale cattle-farming, currently represent major colonization schemes in the Amazon and correspond to important foci of malaria. Also, forests

These schemes and Meroe Dam are served by roads network (table 5) which are linked by many bridges including Friendship Bridge linking Merow and Karima (432m), Dongola - Suleim (693m), Damar – Umeltuer - Akad (858m), Shendi - Metama (660m), Daba - Argi (466m), and Kasinger – Meroe Dam railway. In addition, Merowe International Airport, Merowe Hospital, Merowe Technical College were built to serve the population. These roads are expected to facilitate flow of production and people who might be carriers and hosts of malaria parasite (Dams Implementation Unit, 2019).

Discussion

A. Arabiensis is opportunistic feeder and efficient vector of Plasmodium falciparum in Africa and may invade areas outside its normal range, including areas separated by expanses of barren desert, and the models used reveal large areas of future habitat connectivity that may facilitate the re-invasion of A. Arabiensis from Sudan into Upper Egypt (Fuller et al., 2012). Malaria is currently a serious health problem in Sudan and one which appears to be getting worse since it is threatening Sudan's desert land through vast agricultural expansion and building of new dams. These recent expansions, as exemplified by Northern and River States, could hold suggestions for spatial shifting of malaria endemicity from hypoendemic to mesoendemic in both the States to become similar to central Sudan. Relevant research results could rationalize for that particularly where "the association of malaria with irrigation in arid lands has been known in ancient and recent history" (Farid,1977) and that increased numbers of vectors following irrigation can lead to increased malaria in desert fringes (Ijumba, 2001).

The Northern and River Nile States have witnessed major environmental transitions since the last glacial maximum, 18000 years ago, from hyper arid desert to tropical grasslands, then to semi-desert and back to tropical desert today. Human activities and settlements patterns changed markedly with the rise and fall of kingdoms. These factors will have facilitated the spread of mosquito populations and then, by 1500 years ago, contributed to their reduction, or demise. A. Arabiensis exhibits considerable ecological and behavioural plasticity allowing it to survive in harsh conditions of arid regions. The "saqia" water wheel introduced at the medieval times brought an expansion of human population along the Nile and presumably a gradual reappearance of mosquitoes which continued with occasional setbacks to the present day. Anopheles arabiensis is the only anopheline to have been found between the second and fifth cataract and that it has remained limited to the south of Wadi Halfa over the last century with only intermittent forays into Egypt, where it caused at least two serious outbreaks (Malcolm et al., 2007). Isolation was almost complete except for limited dispersal downriver via the Abu Hamad reach (Malcolm et al., 2007). There was an inverse relationship between the Nile water level and A. Arabiensis production along the River Nile from Dongola where productive breeding in riverside pools was the main source of A. Arabiensis as the river receded (Dukeen and Omer, 1986).

In semi arid Khartoum State, agricultural schemes provided 25% of mosquito breeding sites and perhaps 86% of these schemes' dwellers are infected with the malaria parasite (Khartoum State Ministry of Health, 1996). This was, as well observed in the new irrigation areas in the State's close proximity (El-Sayed et al., 2000), and particularly more noticed in Khartoum North which is almost surrounded by irrigation schemes (Davies, 1991) as accounted for the higher malaria incidence recorded in Khartoum State (Hag Ahmed, 1991). This was similarly noticed by Himeiden et al. (2011) in semi-arid eastern Sudan where a difference in pattern of malaria transmission was noticed between non-irrigated and irrigated areas. It was even more noticed in Wadi Halfa irrigated area where transmission and intensity of malaria is by Dam Implementation Unit, Sudan. These Dams will irrigate the proposed agricultural extensions in the Northern State (Table 4).

Name of Agricultural Scheme	Location Description	Length Km.
Goleid West	Close to Dongola-Khartoum-Highway and Dongola Airport	-
Argein – Gamei	Close to asphalt roads and railways and air transport	-
khuwei for agricultural production	Close to Dongola-Khartoum-Highway and Dongola Airport	-
khuwei Scheme for Animal Production	Close to Dongola-Khartoum-Highway and Dongola Airport	-
Kuka plain	-	-
Alfida	Abu Hamad-Atbara Highway, Challenge Road to Port Sudan and railways, all roads connecting the capital Khartoum with all states of Sudan	-
Gihad	Asphalt roads and railways	-
Wadi el Sheikh for mixed agriculture	Abu Hamad-Atbara – Khartoum Highway, then Challenge Road Atbara–Haya-Port Sudan and railways, all roads connecting the capital Khartoum with all states of Sudan	-
Wadi Naga3a	Asphalt and country roads connecting River Nile state with Khartoum capital and Challenge road connecting the state with Port Sudan	-
Merowe- Dam	Connecting Merowe town with the dam	36
Karima-Dam	Connecting Karima town with the dam	27
Karima- Nawa	Connecting the two towns	180
Shirian el Shimal	Connecting Khartoum city with many towns	254
Merowe- Multaga	Multaga is a nodal point for many roads (Shirian, etc.)	94
Merowe- Atbara	Connecting two towns	262
Karima-Sulaim-Dongola	Connecting three areas	180
Dogola-Wadi Halfa	Connecting two towns	412
Dongola - Khartoum	Connecting Capital of Sudan with all the Northern state	500

Table (5): Road network serving the new agricultural schemes
in Northern and River Nile States
Source: Dams Implementation Unit Sudan. http://www.diu.gov.sd

khuwei for Agricultural Production	South of Sulaim basin – Dongola locality	200,000	Nile water or artesian wells
khuwei for Animal Production	khuwei Wadi – Dongola locality	250,000	Flood irrigation and surface wells
Kuka plain	Wadi Halfa locality , west of the Nile	56,000	Nile water
Alfida	Abu Hamad locality, River Nile state	30,000	Nile water
Gihad	Shendi, River Nile state	4,000	Nile water
Wadi el Sheikh for mixed agriculture	Abu Hamad locality, River Nile state	13,000	Nile water
Wadi Naga3a	West of the Nile, near Matama town	100,000	Nile water
Hamdab el Gadida	Meroei area	35,000	Nile water
Amri el Gadida	Meroe area	67,000	Nile water
Manaseir el Gadida	Meroei area	60,000	Nile water
Kehaila east	Meroei area	45,000	Nile water
Total Area		1,116,000	

Source: http://www.diu.gov.sd

Table (4): Proposed Agricultural extensions for Artesian Irrigation in Northern and River Nile States

Name of a scheme	Area(Feddans)	Name of a scheme	Area (Feddans)
Khwei and Silaim Basin	320,000	Naga3 Wadi	200,000
West Dongola plains (Akaadm Ga3ab)	15,000	Mkabrab Wadi	85,000
Bakri and Rumi plain	15,000	Hawad Wadi	50,000
Latti basin	10,000	Lower Atbara River	40,000
Afad and Argi basin	10,000	Wadi Sial plains- West of the River Nile	5,000
Wadi Magadem	50,000	Khelaiwa – Barber area	4,000
Total	840,000		

Source: Niema Abdelkhali Mustafa. 2015. Climate change, enhancement of African environmental coping systems, Omla Printing Press, Khartoum, p. 24.

Meroe dam was constructed by 346 km far north of the capital Khartoum and by 330 km of the northern borders of Sudan. Huge reservoir of water was created behind the dam extending for 176 km from the fourth cataract up to south Abu Hamad area in a desert area where new agricultural schemes and villages have developed (Dams Implementation Unit, 2019). In addition to Meroe Dam, some other Dams including Kagbar north of Dongola town and Dal south of Halfa town were proposed to be built

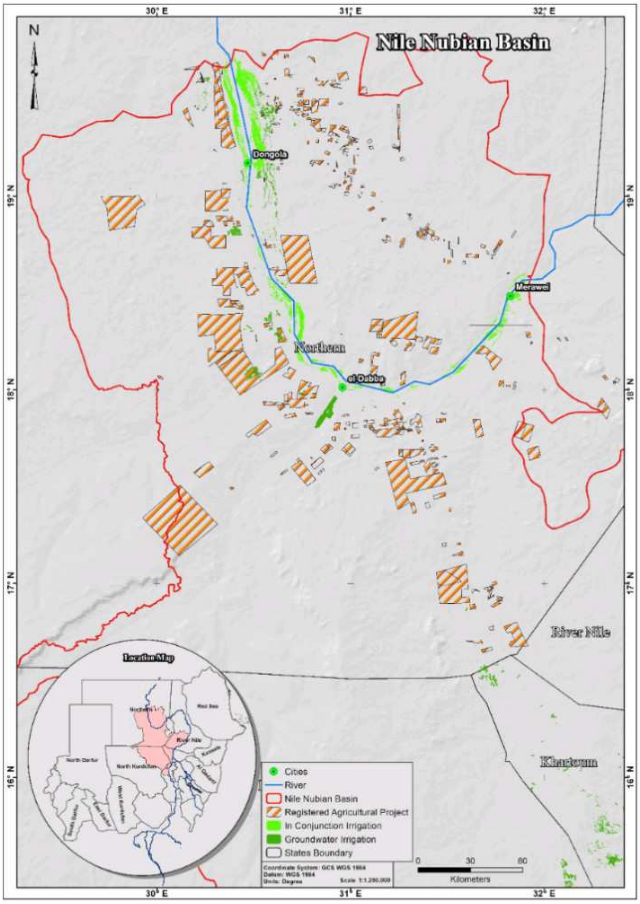

Figure 6: New agricultural schemes in Northern State
Source: Tekno Consultancy Company, 2019

Table3: New agricultural extensions in Northern and River Nile states

Name	Location	Area (Fadden)	Irrigation
Goleid West	South of Dongola area West of the River Nile	50,000	Nile water or artesian water or drip, axial, flash irrigation
Argein – Gamei	Gami plain west of Halfa town on the western bank of River Nile, lies within the Nubian Basin for complementary irrigation	200,000	Direct pumping from the River Nile

systems were applied (Table 2) with dominance of private schemes extending along the River Nile, while many other schemes were irrigated by artesian water (Table 2).

Table (2): Agricultural systems in the Northern State

Agricultural systems	number	Cultivated area (Feddans)
Co-operative societies	159	116720
Agricultural companies	55	135900
Nile private agricultural schemes	7647	93985
Artesian private agricultural schemes	15,131	120486
Total	22,992	467091

Source: Northern State, Ministry of Agriculture, Dongola, 2008

The the total area suitable for agriculture utilization in the Northern State was 352,419 feddans. 49.2% of that area was utilized by 182 governmental and privately owned agricultural schemes while 50.8% remained uncultivated (Northern State, Ministry of Agriculture and Animal Resources and Irrigation, 2008). Over the remaining and newly introduced lands recent agricultural expansion took place (Tables 3) by National private sector and Arab investment (Figure 6). Some of these schemes extend along the River Nile (Table 3) with a total area of 1,116,000 feddans beside some proposed ones with an estimated total area of 840,000 feddans into adjacent desert's fertile lands to depend on artesian water for irrigation (Table 4 and Figure 6). So, the estimated grand total of all agricultural expansion is 1,956,000 feddans and is expected to reach more than 2,000,000 feddans by the largest centre-pivot irrigated alfalfa farms across 87,200 hectares in Wad Hamid area (US-Sudan Business Council, 2018).

rocks (Ahmad et al., 1984). These basement complex rocks are exposed along the course of the Nile and in the central part of the State which are mostly in the form of N-S elongated exposure while Aeolian deposits consist of dune, inter-dune and sand sheets (Abuzeid, et al., 2017). This harsh geologic environment is expected to be participatory influencing malaria incidence like climate; however, the intervening factors have to be considered.

Data sources were Dams Implementation Unit, Sudan (diu.gov.sd), Federal Ministry of Agriculture, Federal Ministry of Health, and National Centre for Health Information (NCHI.Gov. Sd.), Tekno Consultancy Company, relevant books on geology and climate of Sudan, and relevant scientific research on Google Scholar. The comparative and analytical approaches were applied to justify the research problem. The east-west line extending along the southern parts of the desert and separating hypoendemic from mesoendemic malaria zone was taken as the datum for the statement of this study. The relevant research results at national, regional, and international levels were used to rationalize this research statement.

The proposed model (Figure 5) consists of six integral parts, without priority of ordering, to achieve model proposed purposes and purposively work to try keeping arid Sudan, as exemplified by Northern and River Nile States, as hypoendemic area rather than to become a mesoendemic area of malaria endemicity, and also to contribute into future complete eradication of malaria.

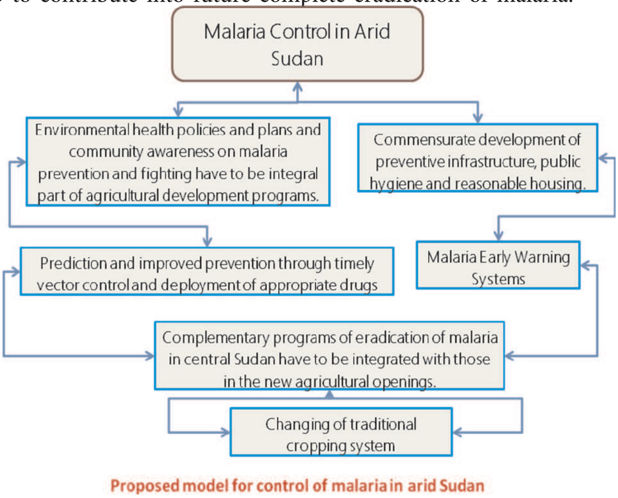

Figure 5: A Proposed model for control of malaria in arid Sudan

Agricultural expansion in the Northern and River Nile States

The total agricultural area in the Northern State was estimated as 14 million feddans where 49% are arable land (Ministry of Financce, Northern State, 2003:25). Types of soils in the Northern State according to Musned (2000) include Desert; Riverain; lands of recent flood plain and flood lands (covered by Nile water annually); mid-terrace lands (irrigated by water pumps and relatively remote from the Nile); high-terrace lands (remote from the Nile and never reached by flood water and they were part of flood plain lands but erosion factors have changed their contour); and soils of old Nile channels and their tributaries such as Wadi Mugadem and Wadi Ga'ab which are characterized by fertile loamy soil. Many agricultural

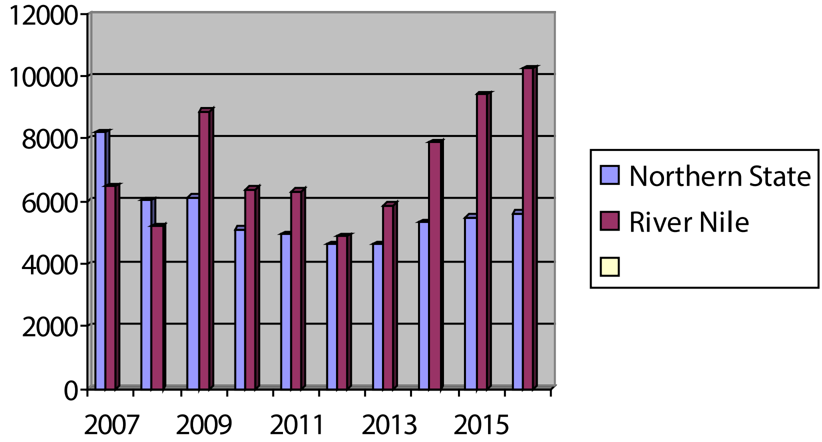

Figure 4: Malaria Inpatient in Northern and River Nile States: 2007-2017
Source: Federal Ministry of Health, 2017

Study area and Methods

The Northern state with an area of approximately 348,765 km^2, lies between latitudes16°N and 22°N; and longitudes 20°E and 32°E provides huge area for mosquitoes to niche. This is enhanced by the River Nile which bisected the two States. Both banks of the River Nile are occupied by population whom were estimated at 699,065 inhabitants in the Northern State, 80% of them live in rural areas; and some others are nomads, giving a total density of 2 persons /km^2 (Ministry of Finance and Economic Planning, 2008). The River Nile State lies between latitudes 16^0 N and 22^0 N and longitudes 32^0 E and 35^0 E. The two States lie within the desert climatic region of Sudan). The Minimum average temperature is witnessed during January which might be below 10 C ^{0}. The maximum average temperature exceeds 40 Celsius degree during summer months of April, May, and June, July and August, due to absence of clouds and the prevalence of dry northeast winds. Therefore, they receive the highest levels of solar irradiation over the Sudan. Annual rainfall is infrequent and ranges between 200 mm to 25 mm northwards which means very low humidity levels and a poor sparse desert vegetative cover. The two states are also under higher onsets of desertification and sand encroachment which excavate the desert climatic conditions. These general climatic conditions might seem to be hostile for malaria mosquitoes; however, factors such as that A. Arabiensis exhibits considerable ecological and behavioral plasticity allowing it to survive in harsh conditions of arid regions, changing climatic conditions and recent expansion of agricultural schemes and building of dams.

Vast expanses of eolian sands are prevailing in the north-western parts of the Northern state and west of the Nile. There are small outcrops of sandstones and conglomerates with some limestone and cherts. Some cross-bedded of sandstones were also noted west of the River Nile between latitudes 20° and 21° N, and in the northwest corner of the Sudan. Nubian sandstone outcrops overlie the basement complex

2017) the Northern and River Nile States still keeping a higher record in malaria incidence (Figure 4) although annual increase of the population in the Northern was 2.1% and came last in ordering of Sudan's States by population number (Ministry of Finance and Economic Planning, 2008). In the view of this study, high records in malaria incidence in the two States are not thoroughly due to increase of population or good reporting to hospitals, but to new agricultural expansion and building of dams in both States.

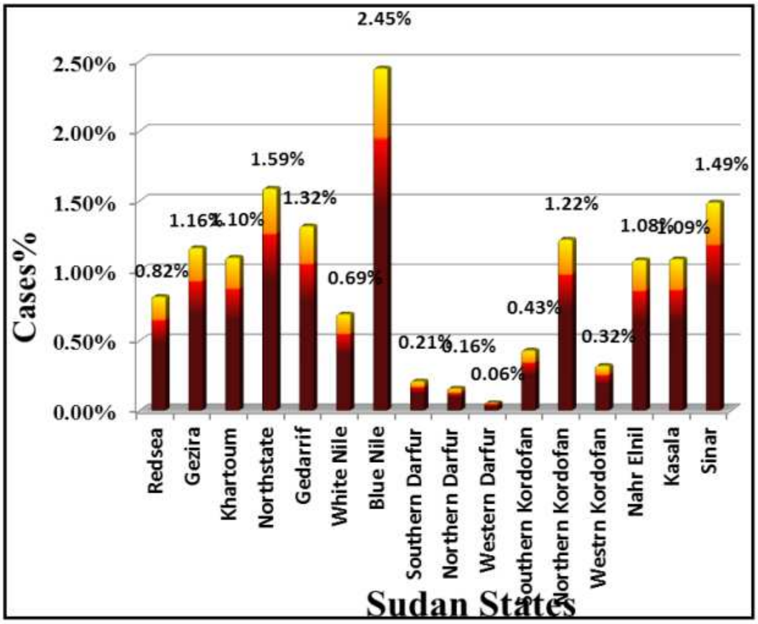

Figure3: malaria cases among Sudan States 1997-2007

Source: Aal A.R. and Elshayeb A.A.2011. The effects of climate changes of the distribution and spread of malaria in Sudan. American journal of environmental engineering 1(1):15-20

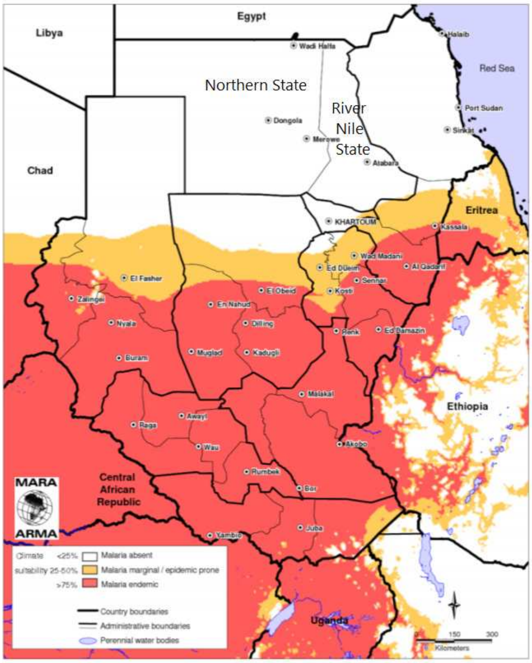

Figure2. Distribution of malaria in Sudan

Source: After Aal A.R. and Elshayeb A.A. 2011. The effects of climate changes of the distribution and spread of malaria in Sudan. American journal of environmental engineering 1(1):15-2

Table1. Malaria epidemiology in Sudan

strata	classification	Annual parasite incidence	Number of population	Malaria intensity
Desert fringe	Hypoendemic	3.8	1,000,000	Unstable
Poor savannah	Mesoendemic	4.8	20,000,000	Unstable
Rich wet savannah	Hyperendemic	1.5	4,000,000	stable
Urban malaria	Mesoendemic	0.3	5,000,000	Unstable

Source: Aal A.R. and Elshayeb A.A.2011. The effects of climate changes of the distribution and spread of malaria in Sudan. American journal of environmental engineering 1(1):15-20

The research problem

In 1995 malaria topped the list of disease admissions to Sudan's hospitals and it was the major disease killing children less than 4 years of age, accounting for more than one third of all hospital deaths for this age group (Ministry of Health, 1995). During the period 1997-2007 (Figure 3) the Northern State came second to the Blue Nile State in malaria cases although they differ significantly in climatic conditions. The River Nile State (Nahr Elnil) is almost similar to Kasala and Khartoum States which lay into somehow rainy zone in central Sudan. During the period 2007-2017 (Federal Ministry of Health, at least to keep them hypoendemic rather than to become mesoendemic areas of malaria endemicity. Malaria endemicity in Sudan

In Lysenko and Semashko map of malaria endemicity (Figure 1) the desert of Sudan is malaria free. Hypoendemic malaria restricts to the River Nile and includes a very small area from the northern parts of central Sudan. Southwards from hypoendemic zone malaria becomes mesoendemic in central Sudan and then hyperendemic in the former south Sudan (Lysenko et al., 1968). Malik and Khalifa (2004) indicated to south Sudan as holoendemic and that 80% of Sudan's population are living in epidemic-prone area-unstable malaria transmission. Aal and Elshayeb (2011) produced a map (Figure 2) and table (table1) for malaria epidemiology in Sudan which agrees with Lysenko's map (Figure 1) and Malik and Khalifa (2004) while introduced urban malaria as mesoendemic similar to central Sudan. The whole of central Sudan, as far north as Atbara town on the main Nile, has climatic conditions conductive to the spread of malaria (Dutt et al., 1978). The dominant species of malaria-carrying mosquito is anopheles arabiensis and the main parasite involved is Plasmodium falciparum, the main cause of malignant tertian malaria (Hamad, 2002). In 2010 the majority of the geographical area of the Sudan had risk of <1% PFPR 2-10. And about 80% of Sudan's population was in the areas in the desert, urban centres, or where risk was <1% PfPR 2 (Abdisalan et al., 2012).

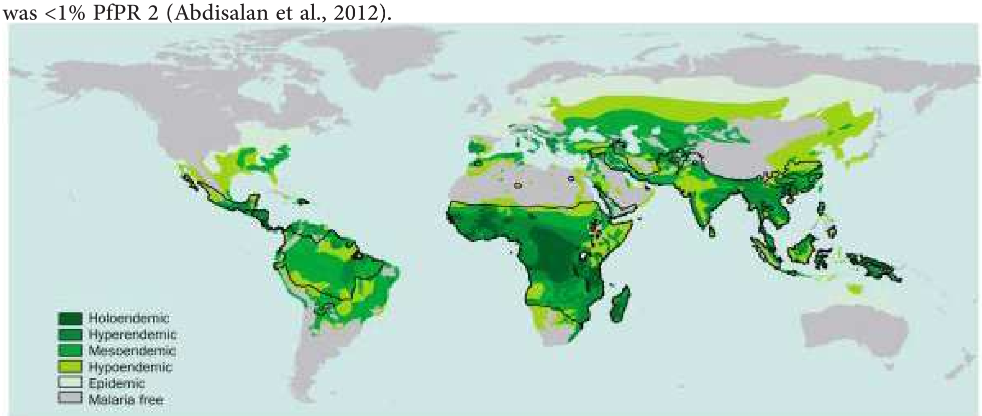

Fig.1. Global map of malaria endemicity

Source: Lysenko A J. and Semashko I N. 1968.

2001). The best conditions for the anopheles are said to lie in temperature between 25^0 and 35^0 C, with relative humidity at 60% and rainy season of at least three months. Temperatures below 16^0 C and above 37^0 C are not so conductive to their survival (Akhtar et al., 1977). The degree of efficiency of malaria vectors to transmit malaria from one human to another is an important factor defining the distribution of malaria in Africa. The distribution of malaria is most influenced by its mosquito vector, which is sensitive to extrinsic environmental factors such as rainfall and temperature. Temperature also affects the development rate of the malaria parasite in the mosquito (Leahman et al., 2010). Because environmental variables are mostly correlated in space, significant spatial association is expected in the spatial patterns of the malaria (Osei et al., 2015).

No recent global maps of malaria endemicity have been developed since those of Lysenko in 1968, despite significant advances in the collection of empirical data, global environmental information from satellites, and the statistical techniques that can be used to integrate them (Simon et al.,2004). Endemicity of malaria as used by Lysenko was defined by the parasite rate in the 2–10-year age cohort (hypoendemic <0·1; mesoendemic 0·11–0·5; hyperendemic 0·51–0·75), except the holoendemic class (>0·75) where the parasite rate refers to the 1-year age group (Metselaar et al., 1959).

A change in the distribution of malaria is foreseeable due to the potential consequences of anthropogenic climate change. An increase in the Earth's temperature and precipitation can create conditions more conducive for the breeding of the malarial vectors. Some studies suggest that climate change can alter the distribution of vector-borne diseases, including malaria, causing regions that are currently free of such diseases to be affected. Thus, climate change could extend the distribution of the Anopheles vector, which is found worldwide except in very cold regions, such as Antarctica. "The considerable change in land-use practices resulting from increasing irrigation in recent decades raises important questions on concomitant change in malaria dynamics and its coupling to climate forcing. Irrigation can lead to more endemic conditions for malaria, creating the potential for unexpectedly large epidemics in response to excess rainfall" (Baeza et al., 2011).

Demographic factors and despite human activities have reduced by half the land area supporting malaria, demographic changes resulted in a 2 billion increase in the total population exposed to malaria risk (Simon, et al.,2004). Although population growth will not substantially change the regional distribution of people at malaria risk, around 400 million births will occur within the boundary of current distribution of malaria by 2010 (Simon, et al.,2004).

"Human- made ecologic transformations such as water resource development projects has led to a history of facilitating a change in the frequency and transmission dynamics of malaria due to proximity to irrigation schemes. Whether an individual water project triggers an increase in malaria transmission depends on the contextual determinants of malaria including the epidemiologic setting, socioeconomic factors, vector management, and health seeking behaviour" (Keiser et al., 2005). The high rates of population growth in Sudan and the demand for food have increased the area under agricultural production including reclamation of arid and semi arid lands and consequently malaria is associated with irrigation schemes.

The objective of this paper is show that agricultural expansion and building of dams into the desert of Sudan will spatially shift endemicity of malaria from hypoendemic to mesoendemic similar to the irrigated area in central Sudan. It also objects to propose a model for malaria control is these arid lands

Abstract

Malaria is a serious tropical disease disrupting the social and economic life of many African communities. Malaria endemicity was classified into hypoendemic, mesoendemic, and hyperendemic with increasing degree of severity. Hypoendemic malaria restricts to the River Nile and a very small area from the northern parts of central Sudan. Southwards from hypoendemic zone malaria becomes mesoendemic in central Sudan and then hyperendemic in the former south Sudan. This study was based on the statement that, agricultural expansion and building of dams into the desert of Northern and River Nile States of Sudan will spatially shift malaria endemicity from hypoendemic type to mesoendemic type. Sources of data included, published information by National Centre for Health Information, Federal Ministry of Agriculture, Dams Implementation Unit - Sudan, relevant books on geology and climate of Sudan, and relevant scientific research on the Internet. Comparative and analytical approaches were applied. Results suggested for high expectancy of shifting of malaria from hypoendemic to mesoendemic when during the period 1997-2007 the Northern State came second to the Blue Nile State in malaria cases although they differ significantly in climatic conditions. The estimated grand total of all agricultural expansion was 1,956,000 feddans and was expected to reach more than 2,000,000 feddans by the largest centre-pivot irrigated alfalfa farms across 87,200 hectares in Wad Hamid area. Meroe Dam created a huge reservoir of water extending for 176 km from the fourth cataract up to south Abu Hamad area where new agricultural schemes and villages have developed. It is expected also that, a geographic corridor of mesoendemic malaria will be created to link River Nile and Northern States with southern Egypt and Mediterranean lands northwards, and interior Africa southwards. Relevant scientific research in Sudan, Africa and Asia supported these suggestions where "the association of malaria with irrigation in arid lands has been known in ancient and recent history" and that increased numbers of vectors following irrigation can lead to increased malaria in desert fringes. The study proposed a model for controlling of malaria in arid Sudan purposively to keep it hypoendemic rather than to become a mesoendemic of malaria endemicity.

Key words: malaria, endemicity, geographic shift, agricultural expansion, desert environment,

Malaria is a serious tropical disease disrupting the social and economic life of many African communities in both rural and urban areas. It is estimated that malaria threatens the lives of 40% of the world's population and is a public health problem in more than 90 countries to varying degrees (World Health Organization, 2012, 2015); a serious parasitic disease worldwide (Yongze et al.,2016) and one of the largest obstacles to socioeconomic advancement (WHO, 2016). In AFRO area the population at risk grew from 0·06–0·65 billion during the 20th century, more than 80% of whom remain in areas of hyperendemic and holoendemic malaria (Carter et al., 2002).

Plasmodium is the agent of the disease and of its various forms the most serious is Plasmodium falciparum which on average proves fatal in 10% of cases caused by it (Meade et al., 1988). The vector by which the disease is transmitted is the anopheles mosquito. As the breeding sites for the mosquito are stagnant water, malaria was originally associated with rural rather than urban areas. Large areas of the world have climatic conditions conductive to breeding of malarial mosquitoes, including not only tropical lands but also many areas with warm temperature and Mediterranean–type climates (Prothero,

Expectancy of Shifting Malaria Endemicity from Hypoendemic to Mesoendemic with Agricultural Expansion into Deserts of Sudan

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مستخلص

تعتبر الملاريا أحد الأمراض المدارية التي تعمل على اضطراب الحيأة الاقتصادية والاجتماعية للعديد من المجتمعات الأفريقية. يُصنف توطن الملاريا مع إزدياد حدتها إلى «هايبواندميك» و»ميسواندميك» و»هايبراندميك». يقتصر توطن الملاريا «هايبواندميك» على نهر النيل ومنطقة صغيرة جداً من الأجزاء الشمالية لوسط السودان. إلى الجنوب من نطاق الملاريا «هايبواندميك» يصبح توطن الملاريا من نوع «ميسواندميك» في وسط السودان، ومن ثم يصبح «هايبراندميك» في جنوب السودان السابق. اعتمدت هذه الدراسة على فرضية أن التوسع الزراعي وبناء السدود في صحراء ولايتي نهر النيل والشمالية سينقل توطن الملاريا مكانياً من نوع «هايبواندميك» إلى «ميسواندميك». شملت مصادر البيانات المعلومات المنشورة بواسطة المركز القومي للمعلومات الصحية، ووزارة الزراعة الإتحادية، ووحدة بناء السدود- السودان، والكتب ذات الصلة بجيولوجيا ومناخ السودان، والبحوث العلميّة ذات الصلة والمنشورة على الإنترنت. تم تطبيق المنهجين المقارن والتحليلي. أوحت النتائج توقعية عالية لإنتقال الملاريا من نوع التوطن» هايبواندميك» إلى النوع « ميسواندميك» حيث أتت الولاية الشمالية في الفترة ١٩٩٧-٢٠٠٧ في المرتبة الثانية بعد ولاية النيل الأزرق في حالات الإصابة بالملاريا رغم إختلافهما الجوهري في الأحوال المناخية. بلغ المجموع الكلي للتوسع الزراعي ١,٩٥٦,٠٠٠ فداناً، ويتوقع أن يصل إلى ٢,٠٠٠,٠٠٠ فداناً بمشروع مزراع ألفاألفا المركزية بمساحة ٨٧٠٠٠ فداناً في منطقة ود حامد. أوجد خزان مروي بحيرةً عظيمة تمتد لمسافة ١٧٦ كيلومتراً من الشلال الرابع إلى جنوب أبو حمد حيث نشأت المشاريع الزراعية والقرى. من المتوقع أيضاً أن يوجد ممر جغرافي لتوطن الملاريا «ميسواندميك» يربط ولايتي نهر النيل والشمالية بجنوب مصر وأراضي البحر الأبيض المتوسط شمالاً، والداخل الأفريقي جنوباً. ويدعم البحث العلمي في السودان وأفريقيا وآسيا هذه الافتراضات حيث « عرف الإرتباط بين الملاريا والريّ في التاريخ القديم والحديث وأن الزيادة في أعداد النواقل التي تأتي مع الريّ يمكن أن تزيد الملاريا في تخوم الصحراء». أقترحت الدراسة نموذجاً للسيطرة على الملاريا في مناطق السودان الجاف بغرض الحفاظ عليها «هايبواندميك» من أن تصبح «ميسواندميك» لتوطن الملاريا.