International Journal of Water Resources and Environmental Engineering

Volume 9 Number 2 February 2017

ISSN-2141-6613

Academic Journals

ABOUT IJWREE

The International Journal of Water Resources and Environmental Engineering is published monthly (one volume per year) by Academic Journals.

International Journal of Water Resources and Environmental Engineering (IJWREE) is an open access journal that provides rapid publication (monthly) of articles in all areas of the subject such as water resources management, waste management, ozone depletion, Kinetic Processes in Materials, strength of building materials, global warming etc. The Journal welcomes the submission of manuscripts that meet the general criteria of significance and scientific excellence. Papers will be published shortly after acceptance. All articles published in IJWREE are peer-reviewed.

Contact Us

Editorial Office: ijwree@academicjournals.org

Help Desk: helpdesk@academicjournals.org

Website: http://www.academicjournals.org/journal/IJWREE

Submit manuscript online http://ms.academicjournals.me/

Editors

Editorial Board

International Journal of Water Resources and Environmental Engineering

Table of Contents: Volume 9 Number 2 February 2017

ARTICLES

academicJournals

Vol. 9(2), pp. 33-42, February 2017
DOI: 10.5897/IJWREE2016.0692
Article Number: 71AB8CF62500
ISSN 2141-6613

http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Review

Status of wetlands valleyed in a hilly region of North East India - A review

Thiyam Tamphasana Devi*, Bakimchandra Oinam, Ngangbam Romeji Singh and Maisnam Bipinchandra Singh

Department of Civil Engineering, NIT Manipur, Langol-795004, Manipur, India.

Received 7 October, 2016; Accepted 1 December, 2016

A key to future sustenance of human societies lies in the sustainable management and wise use of Wetlands. Wetlands are frequently referred to as *Kidneys of Landscape*; are amongst the most productive ecosystems on the earth and any alterations might lead to changes in their bio-physical, socio-economic and climatic conditions. Due to various factors like rapid urbanization, industrialization and agricultural activities; Wetland ecosystems become the most threatened of all environmental resources on earth. The call for its protection gained in early 1960's globally. However, in India, the momentum for its protection gained only in late 1980's. In order to make effort to restore and protect such degraded Wetlands, its extensive study is required in terms of its ecological changes with its areal extent. There is a huge gap of scientific study about the Wetlands in India especially in this study region (Manipur) and eventually people could not recognise the importance of Wetland services given to mankind. Therefore, this study is aimed at reporting the status of Wetland exists in Manipur (a small state of North-Eastern India surrounded by hilly terrains) as a first step for further studies. The lack of scientific studies about the Wetlands in this particular study region is also reported in this paper.

Key words: Wetlands, Manipur, Sangai, status of wetlands, review, lakes, hilly terrains.

INTRODUCTION

Wetland ecosystems provide significant ecological goods and services to humankind with estimated worth of US$70 billion per annum globally (SACONH, 2004). Wetland are *Wealthlands* and performs valuable function such as; it recycles the nutrient, purifies water, recharges ground water, provides drinking water, fish, fodder, fuel, wildlife habitat, controls rate of runoff in urban area, and acts as a recreation centre in the region (Prabhat and Singh, 2014). Therefore, Wetlands are frequently referred to as *Kidneys of Landscape*; are amongst the most productive ecosystems on the earth (Ghermandi et al., 2008) and at the same time they are ecologically sensitive and adaptive systems (Turner et al., 2000) and any alterations might lead to changes in their bio-

*Corresponding author. Email: thiyam85@gmail.com.

physical, socio-economic and climatic conditions. The global areal extent of Wetland ecosystems (6% of total land surface area of world) ranges from 9.17 million sq.m (Lehner and Doll, 2004) to more than (Finlayson and Spiers, 1999) with an estimated economic value of about US dollar 15 trillion a year (MEA, 2005). Overall 1052 sites in Europe; 289 sites in Asia; 359 sites in Africa; 175 sites in South America; 211 sites in North America; and 79 sites in Oceania region have been identified as Ramsar sites or Wetlands of International importance (Ramsar Secretariat, 2013). In India 0.44% of total land surface area are Wetlands and 26 Wetlands are under Ramsar sites including only one (Loktak Lake) from Manipur even though many other Wetlands which perform potentially valuable functions are continuously ignored in the policy process.

Due to various factors like rapid urbanization, industrialization and agricultural activities; Wetland ecosystems become the most threatened of all environmental resources on earth. Thirty eight percent (38%) of India's Wetlands had already lost in 10 years and many more are under threat (Jain et al., 2011). Wetlands are major carbon sinks and among the first ecosystems to experience the impact of climate change (IPCC, 2000; Mitsch et al., 2009). Many freshwater Wetlands ecosystems are threatened and many are already degraded and lost due to urbanization, population growth and increases economic activities (Annual Report, 2008-2009). The major problems faced by the Wetland are sedimentation and deterioration of the quality of water especially in small water bodies. Such Wetlands performed several economic (fisheries, livestock and forestry), social (water supply), and ecological functions (groundwater recharge, nutrient recycling, and biodiversity maintenance) in the past. Despite all these benefits, many decision-makers and even many of the primary stakeholders think of them as wasteland (Bassi et al., 2014) and therefore everyone claims a stake in them, as they are in the open access regime, but rarely willing to pay for this extractive use (Verma, 2001). The difficulty to distinguish terrestrial and aquatic ecosystems since the latter are periodically waterlogged or submerged for varying periods, thus being a source of confusion amongst scientists (Brij, 1991) is another possible reason for the Government's inability to address the legal and institutional aspects of Wetland management. The call for its protection gained in early 1960's globally. However, in India, the momentum for its protection gained only in late 1980's. In order to make effort to restore and protect such degraded Wetlands, its extensive study is required in terms of its ecological changes with its areal extent, ecosystem benefits they provide and various stresses they are exposed to. There is a huge gap of scientific study about the Wetlands in India especially in this study region (Manipur) despite the fact that North-East falls under Indo-Burma global hotspot, the area harbours large number of Wetlands (Jain et al., 2011). Because of the lack of scientific study, people could not recognise the importance of Wetland services given to humankind.

The major components of Wetland in Manipur are its plants and herbs which are exhaustedly used as domestic and medicinal purposes. Fish is also one of the main livelihood resources of the people of Manipur. "Sangai" an endangered species of deer is inhabitant to one of the major Wetland (Loktak Lake which is a Ramsar site) of Manipur. Loktak and other surrounding smaller lake (such as Pumlen Lake) has the capacity to generate electricity as all the major river and streams falls into these lakes. However, due to urbanization and other modern agricultural activities, these Wetlands are degrading day by day. Therefore, this study is aimed at reporting the status of Wetlands exists in Manipur (a small state of North-Eastern India surrounded by hilly terrains) as a first step for further studies. The lack of scientific studies about the Wetlands in this particular study region is reported in this paper.

Geography of the studied area

Manipur is a small state of north-eastern India mainly comprises of hilly terrain (92%) surrounding by a centrally located saucer shaped valley (1856 km^2). It is bounded by Nagaland to the north, Mizoram to the south, and Assam to the west; Burma lies to its east. The state lies at a latitude of 23°83'N to 25°68'N and a longitude of 93°03'E to 94°78'E. The total area covered by the state is 22,347 km^2. The capital lies in an oval-shaped valley of approximately 2,000 km^2 surrounded by mountains and is at an elevation of 790 metres above sea level. The slope of the valley is from north to south. The mountain ranges create a moderated climate, preventing the cold winds from the north from reaching the valley and barring cyclonic storms originating from the Bay of Bengal (Figure 1).

Manipur may be characterised as two distinct physical regions: an outlying area of rugged hills and narrow valleys, and the inner area of flat plain (where all major Wetlands are in this region), with all associated land forms. These two areas are distinct in physical features and are conspicuous in flora and fauna. The valley region has hills and mounds rising above the flat surface. The state has four major river basins: the Barak River Basin (Barak Valley) to the west, the Manipur River Basin in central Manipur, the Yu River Basin in the east, and a portion of the Lanye River Basin in the north (Haokip, 2007).

RESULTS AND DISCUSSION

The major wetlands of Manipur such as Loktak Lake,

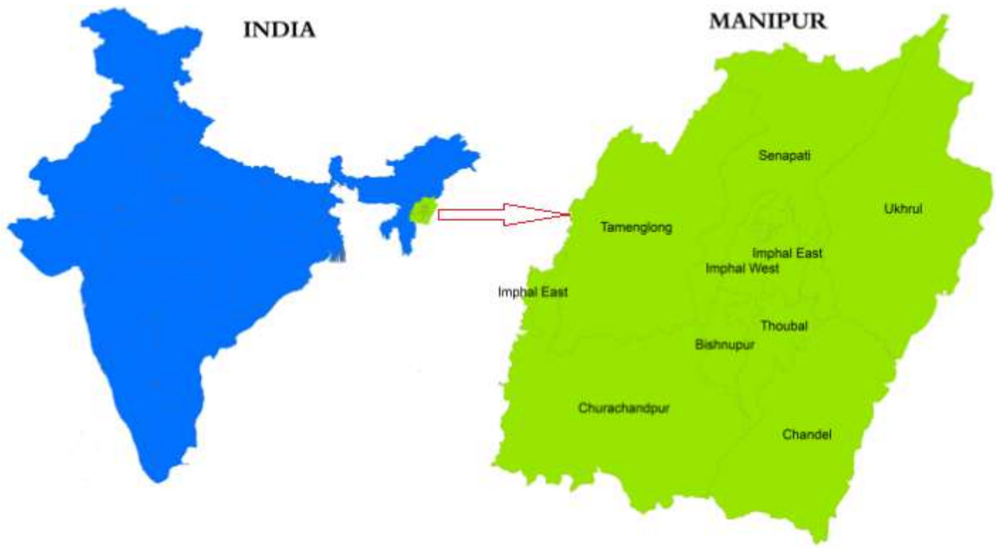

Figure 1. Location of study area.

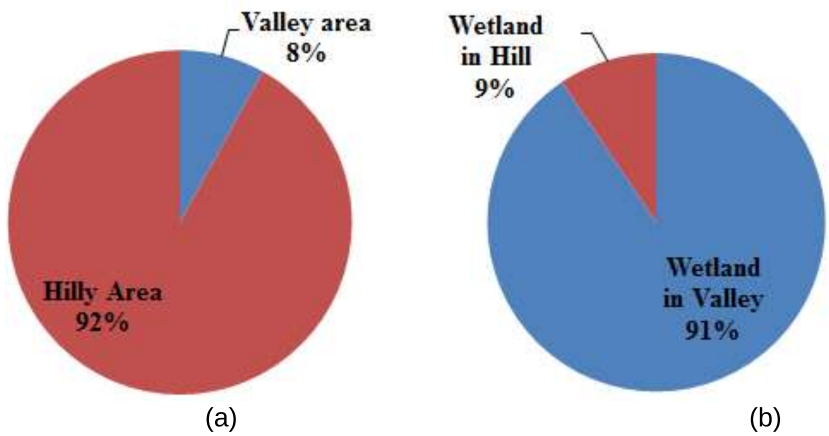

Figure 2. (a) Percentage geographical area covered by hilly terrain and flat valley and (b) percentage area covered by Wetlands in hill and valley regions.

Pumlen Lake and other smaller lakes were discussed in terms of its changes in spatial distribution for the past 40 years. The major components of these Wetlands with its present status based on the services provided to mankind by these Wetlands are also discussed here.

DISTRIBUTION AND EXTENT OF WETLANDS

As Manipur is surrounded by hilly terrains (92%), major Wetlands concentrated in the central valley of the state (about more than 90%). Figure 2 shows the (a) percentage geographical area covered by hilly terrain and flat valley and (b) percentage area covered by Wetlands in hill and valley regions.

There are nine administrative districts in the state in which 4 districts viz., Imphal East, Imphal West, Thoubal and Bishnupur comprises in the Valley region; and the rest five districts viz., Ukhrul, Chandel, Tamenglong, Senapati and Churachanpur covers the hilly terrain. The number of Wetlands and their distribution varies in different studies reported by different researchers and government organizations mainly because of their consideration of different criteria in defining of Wetlands and ignorance of smaller wetlands (Figure 3). Figure 3 shows the total area covered by Wetlands in the state identified by different govt. organizations (column chart) and its percentage contribution to the total area (pie

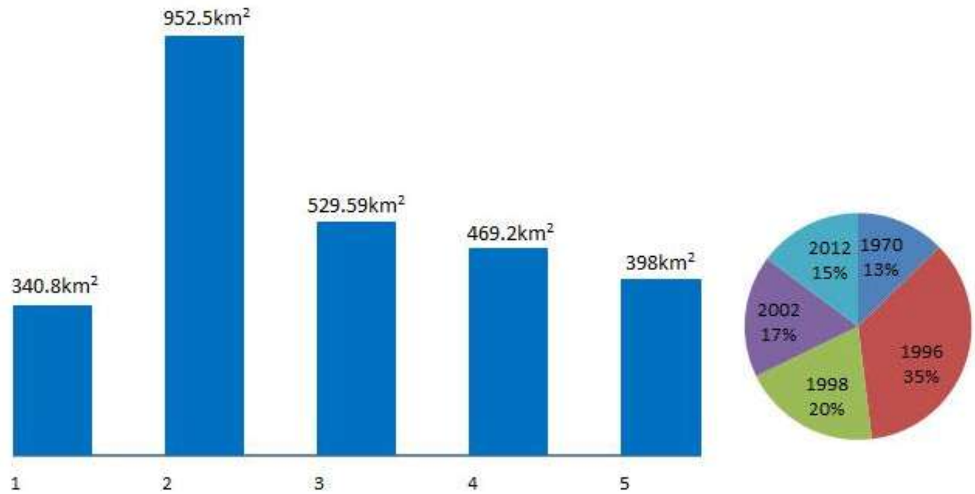

Figure 3. Total area covered by Wetlands in the state identified by different govt. organizations (column chart) and its percentage contribution to the total area (pie chart). Source: 1 - Wetland International South East Asia (WISA) (1970); 2 - Fishery Department, Government of Manipur (1996); 3 - Space Application Centre (SAC), Government of India (1998); 4 - Wetland International South East Asia (WISA) (2002); 5 - Environmental Information System (ENVIS) Centre, Government of Manipur (2012).

Table 1. District-wise distribution of Wetlands in Manipur (1996).

S/No.	Districts	Wetlands area (km^2)					
		Ponds/Tanks	Lakes/Swamps/Beels	Reservoirs	Paddycum Fish culture	Total	Rank
1	Imphal (East and West)	12.50	20.00	10.00	900.00	132.50 (13.91)	3
2	Thoubal	15.00	80.00	10.00	150.00	255.00 (26.77)	2
3	Bishnupur	1500	290.00	10.00	160.00	475.00 (49.87)	1
Totalvalley districts		**42.50(4.93)**	**390.00 (45.22)**	**30.00(3.43)**	**400.00 (46.37)**	**862.50 (90.55)**	
1	Ukhrul	1.50	0.50	14.00	2.00	18.00 (1.89)	5
2	Senapati	1.50	0.50	14.00	2.00	18.00 (1.89)	5
3	Churachandpur	2.00	0.50	14.00	2.00	18.50 (1.94)	4
4	Chandel	1.50	0.50	14.00	2.00	18.00 (1.89)	5
5	Tamenglong	1.50	0.50	14.00	2.00	17.50 (1.84)	6
Total hill districts		**7.50 (8.33)**	**2.50 (2.77)**	**70.00 (77.77)**	**10.00 (11.11)**	**90.00 (9.44)**	
Total Manipur		**50.00 (5.25)**	**392.50 (41.21)**	**100.00 (10.50)**	**410.00 (43.04)**	**952.50 (100)**	

*Figures in brackets are percentages to the total. Source: Annual Report (1996), Fishery Department, Government of Manipur.

chart). Even though there is variation in covering of Wetlands in different studies, it is indeed witnessed from Figure 2 that wetland covering area is decreasing except in the year 1996 reported (35%) by Fishery Department, Government of Manipur. As per the latest study done by ENVIS Centre, Government of Manipur (ENVIS, 2012), there is only 15% contribution of Wetlands to the total geographical area of the state.

Table 1 shows the district-wise distribution of Wetlands in Manipur reported by Fisheries Department, Government of Manipur (Wetlands in Manipur, 1996). Figure 4 shows the (a) district-wise distribution of Wetland and (b) distribution by types of Wetlands. According to their report (Table 1 and Figure 4), Wetlands occur in the form of ponds or lakes (5.25%), reservoirs (10.50%), lakes or swamps of beels (41.21%) and paddy

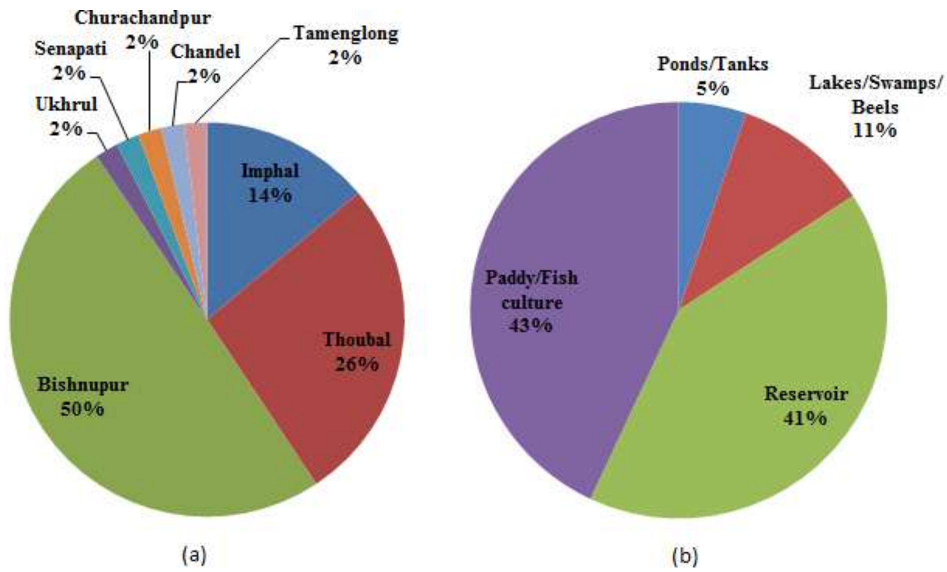

Figure 4. (a) District-wise distribution of Wetland (b) distribution by types of Wetland (Fishery Department, Government of Manipur).

Table 2. Distribution of Wetlands in Manipur (1996).

Districts	Wetland category	Total number of Wetland	Area (km²)	Water spread aquatic (km²)	
				Post-Monsoon	Pre-Monsoon
Bishnupur	1. Lakes	4	179.79	108.77	79.69
	2. Waterlogged	21	19.265	19.265	0.00
Sub-total		**25**	**199.055**	**128.085**	**79.69**
	1. Lakes	7	166.95	22.11	17.28
Thoubal	2. Ox-bow lakes	2	0.35	0.35	0.20
	3. Waterlogged	40	29.58	29.58	0.00
Sub-total		**49**	**196.88**	**52.04**	**17.48**
Imphal (East and West)	1. Lakes	10	86.84	14.60	8.87
	2. Waterlogged	69	45.815	36.785	0.00
Sub-total		**79**	**132.655**	**51.385**	**8.87**
Senapati	Reservoir	1	0.20	0.20	0.12
Tamenglong	Reservoir	1	0.80	0.80	0.45
Total hill districts		**2**	**1.00**	**1.00**	**0.57**
Total Manipur		**155**	**529.59**	**232.46**	**106.61**

Source: Nationwide Wetland Mapping Project, Space Application Centre, Ahmedabad (1998).

cum fish culture areas (43.04%). Table 2 shows the district-wise distribution of Wetlands with its types.

According to Nationwide Wetland Mapping Project, Space Application Centre (ISRO), Ahmedabad (Nationwide Wetland Mapping Project, 1998), Wetlands cover about 529.59 km^2 (about 2.37% of total geographical area of the state). There are 155 Wetlands, of which 153 wetlands covering of 528.59 km^2 (99.81 %) of the total

Table 3. Wetland area within the central valley of Manipur (1970) and (2002).

S/No.	Wetland	District	Area (km^2)	
			1970	2002
1	Loktak Lake	Bishnupur/Imphal West	206.90	287.00
2	Pumlenpat, Khoidumpat, Lamjaopat	Thoubal	58.80	84.00
3	Ikoppat and Kharungpat	Thoubal	47.90	70.50
4	Loushipat	Thoubal	11.30	14.40
5	Waithou and Phumnom Pats	Thoubal	5.00	5.40
6	Other Pats	Bishnupur/Imphal East	9.30	7.50
Total			**340.80**	**469.20**

Source: Wetland International South Asia (2005).

area located in the Central Valley of Manipur, while remaining 2 wetlands covering 1.00 km^2 (0.19%) are located in the hill districts (Table 2).

Table 3 shows the spatial changes of Wetland in central valley of the state and found increasing its total covering area (37.67%). This may be because of the state government initiative to conserve these Wetlands (e.g.; clearing of Phumdis in Loktak Lake and its surrounding lake done by Loktak Development Authority (Annual Administrative Report, 2011-2012)). However, such study was done only for bigger lakes. According to Wetland International South Asia (2005) wetlands of central valley covers approximately about 469 km^2 (20% of the total geographical area).

There are important 19 Wetlands in Manipur identified for conservation and management by the Directorate of Environment, Government of Manipur (Technical report, 2012) and is tabulated in Table 3.

SOCIO-ECONOMIC CONDITIONS OF MAJOR WETLANDS

Total area covered by important Wetlands is approximately 398 km^2 (1.78% of the total area) in which only 1.25 km^2 (0.006%) in the hilly region (Table 4). As per ENVIS report (ENVIS, 2012), there is little contribution of Wetlands in hilly region and major Wetlands are concentrating in central valley surrounded by hilly terrains and subsequently during rainy season, the eroded soils from the hills sediment to this low laying Wetlands. Sediment deposition decreases the depth of Wetlands eventually erasing the beauty and destroying the ecosystem of the Wetlands. Degradation of Wetlands in this particular region may be by many factors apart from sedimentation like deforestation in hills (Jhum cultivation), spread of settlement, increasing use of land resources for agriculture and economic development. To fulfil the increasing demand of agricultural products, use of pesticides has increased quite largely in Indian Green Revolution which started in 1965 in order to become self-sufficient in the production of food grains. Such initiative was considered successful however it affects the aqua life (birds, fish, plants, etc.) of the Wetlands destroying their life cycle and eventually these aqua lives go into extinction (that is, Pengba fish of Manipur). Such activities also deteriorate the quality of water and are a great concern and are more alarming in small water bodies (Bassi et al., 2014). The total water areas in Manipur State have shrunk from around 1000.00 km^2 in 1990 to around 564.615 km^2 in 2009-10 (Ngasepam et al., 2015) that means total area of Wetlands lost is nearly 44% within 20 years. The major cause of ecological problems in Manipur is due to improper planning and lack of integrated approach (Ngasepam et al., 2015). Manipur has potential to produce about 38,000 tonnes of fish; however, at present only 19,200 tonnes is producing (LDA and WISA, 1998) which is against the total requirement of 27,500 tonnes (based on the National Nutritional Standard of 11 kg per capita consumption of fish).

Loktak Lake

Among the Wetland identified for conservation and maintenance, the biggest Wetland (Loktak Lake) is under Ramsar site because of its biological richness, unique ecosystems and habitats. Under the Ramsar Convention Loktak Wetland is designated as “Wetland of International Importance” and directed to the concern authority to conserve, protect and maintain this Wetland. As such Loktak Development Authority (Annual Administrative Report, 2011-2012) which is constituted by the Government of Manipur in 1986 for overall improvement and management of Loktak Lake and its surroundings. The objective of the Authority is to check the deteriorating condition of Loktak Lake and to bring about improvement of the lake ecosystem along with development in the field of fisheries, agriculture and tourism while conserving the

Table 4. Important Wetlands (Major Lakes) of Manipur (2012).

S/No.	Name of the Wetland	Lake Type	District	Area (km^2)(full water level)
1	Loktak Pat (Ramsar Site)	Natural	Bishnupur and Imphal West	246.72
2	Pumlen/khoidum/Lamjao Pat	Natural	Thoubal	80.22
3	Ikop/Karung Pat	Natural	Thoubal	47.63
4	Lousi Pat	Natural	Thoubal	11.35
5	Heingang Pat	Natural	Imphal East	2.75
6	Tankha Pat	Natural	Imphal West	1.29
7	Sanapat	Natural	Bishnupur	1.17
8	Waithou/Punnem Pat	Natural	Thoubal	1.08
9	Utrapat	Natural	Bishnupur	0.86
10	Jaimeng Pat	Natural, Hill Wetland	Senapati	0.85
11	Karam Pat	Natural	Imphal West	0.57
12	Aongbikhong Pat	Natural	Thoubal	0.55
13	Lampel Choi Pat, Andro	Natural	Imphal East	0.55
14	Lamphel Pat	Natural, Urban Lake	Imphal West	0.50
15	Sannapat, Andro	Natural	Imphal East	0.49
16	Ushoipokpi Pat	Natural	Thoubal	0.44
17	Yaral Pat	Natural	Imphal East	0.40
18	Zeilad Pat	Natural, Hill Wetland	Tamenglong	0.20
19	Kayang Kachophung Pat	Natural, Hill Wetland	Ukhrul	0.20
Total=398 km^2				

Source: ENVIS Centre, Directorate of Environment, Government of Manipur (2012); *Pat means lake in local word.

catchment are involving concerned Departments of the State Government. Loktak Development Authority (Annual Administrative Report, 2011-2012) monitors the vast expense of floodplain Wetlands of Manipur River known as Loktak Wetland Complex (including Loktak, Pumlen, Ikop, Kharung and Khoidum). In their Annual Administrative Report (2011-2012) for the Year 2011-2012, it is reported that overall 45 villages and 29 towns are located in and around these Wetlands comprising 71% population of the state living within the Manipur River Basin and 14% alone in and around Loktak Lake. Therefore there is huge contribution by these Wetlands for the livelihood of these people. Loktak Lake Complex has the capacity to provide water for 105 MW Loktak Hydropower Project.

Loktak Lake is famous for its “Floating Phumdi”, floating heterogeneous masses of soil; vegetation and organic matter at various stages of decomposition is a characteristics feature of the Lake. Floating Phumdi spread over 40 km^2 in the southern portion of the Loktak also called Keibul Lamjao National Park is home to the various species most importantly by Sangai (Sangai in local name and Cervus eldi eldi in scientific name), an endangered Manipur brow-antlered deer and is near to extinction (Wetland International South Asia, 2005). The brow-antlered deer was first discovered in Manipur in 1839 and was reported an extinct species in 1951[26]. Sangai are confined to 15 - 20 km^2 in the southwestern part of the lake where phumdis on which the deer lives are abundant. The Sangai distribution dictated by shelter and availability of food is high near Toyaching, Pabotching and the Yang Kokchambi area (Sangsit, 2003). It was re-discovered in the Keibul Lamjao National Park (located in the vicinity of Loktak Lake) area by the environmentalist and photographer Edward Pritchard Gee in 1953 (Wikipedia, 2016). He necessitated declaring this reserve park area as a national park to protect and conserve the deer. Recently, The Manipur Forest Department (2009) also plans to translocate a section of the rare species of the endemic deer to Pumlen Pat (which is close to Loktak Lake), an effort to save Sangai from extinction, the Hindu reported (The Hindu, 2015). By taking conservative measures, it is being said that the population of Sangai increased which is tabulated in Table 5. As per Forest Department officials, around 60 km^2 area is required to accommodate the newly translocated Sanagi and grow their numbers in Pumlen Pat. They confirmed that translocating will be started in the coming two to three years however; there is also a big challenge to acquire the land as the Wetland is encroached upon by fisherfolk and local villagers.

Based on Table 5, the status of Sangai is increasing year by year and is a good sign towards the effort made to protect and conserve this species. Another successful

Table 5. Existing number of Sangai in Keibul Lamjao National Park.

S/No.	Year	No. of Sangai
1	1975	14
2	1990	76
3	1995	155
4	2000	162
5	2003	180
6	2008	100
7	2013	204

Source: Forest Department, Government of Manipur.

captive breeding programme is underway at the Alipore Zoological Gardens in Kolkata, and many specimens of the deer have been bred there (National Zoological Park, 2016).

But ironically, there are other sources: The Wildlife Institute of India (Sangsit, 2003) that believes the figure could be much less. In 2006, 2007 and 2008, it estimated the deer population at 90, 88 and 92, respectively. Dinabandhu Sahoo, director, Institute of Bioresources and Sustainable Development (IBSD), Department of Biotechnology, Imphal also expressed that Sangai is not protected even though it is an integral part of the sociocultural and economic life of the Manipuri people (LiveMint-e Newspaper, 2016).

Water resources development projects for irrigation, flood mitigation, agriculture and hydropower generation for example construction of Ithai barrage converted a naturally fluctuating Wetland into a reservoir leading to inundation of peripheral areas, loss of migratory fisheries, reduction and degradation of national park habitat and decline in water quality (Annual Administrative Report, 2011-2012). Another major problem is siltation which comes from hills due to Jhum (shifting) cultivation and deforestation for human settlement thereby reducing the flood attenuation capacity of the Loktak Lake Complex. Inadequate sewerage system caused inflow of untreated sewage into the lake through the inflowing rivers is another reason for declining in water quality. Declining resource pressures on rising population forced to practice harmful fishing activities thereby causing Phumdi proliferation which made choking the central sector of the lake is another concern. To stop the Wetland ecosystem degradation upto certain limit will account by improving livelihood of people within the Wetland communities.

Pumlen Lake

Pumlen Lake is the second largest fresh water Wetland in Manipur (Ngasepam et al., 2015). It is also the second largest source for fish production. The population around this lake is 469 and 29.74% of people practices fishing as their occupation. The overall fish production of the lake is 1652 kg/yr as per the study of Ngasepam et al. (2015). The study done by Ngasepam et al. (2015) particularly about Pumlen lake based on the socio-economic condition of the fishermen found several reasons for declining in the fish production rate as: (i) inflow of organic chlorine pesticides and chemical fertilizers used in the agriculture activities in and around the lakes, rivers, ponds, beels, etc. (ii) over exploitation and indiscriminate of fishing activities practiced by surrounding people (iii) fast growth of water plants (hyacinth and other weeds) spreading over the entire lake (iv) heavy siltation due to soil erosion from hills and (v) poisoning and poaching of fish. They have pointed out about the sustainable management of the Lake Ecosystem in terms of development of fish production through awareness for modern fish farming techniques and training of fishermen.

Jain et al. (2011) carried out a study of Wetlands of Manipur (Loktak, Sanapat, Utta, Pumlen, Ikop, Waithou, Poirou) based on edible plants with dietary use provided by these Wetlands. They found that the annual volume of estimated edible plants generated from these Wetlands is about 113 tonnes with net revenue of Rs 9 lakh. But, they also reported declining of Wetland edible plants (45% significantly decreased and 35% needs utmost conservation measures) in recent times due to destruction and shrinkage of Wetland habitats at places and also due to erratic rainfall that may cause flood and/or dry condition. They also added that major threat faced by these Wetlands is not only by over-exploitation of fishing but also due to siltation from the surrounding upland, conversion of marginal Wetlands into paddy fields, development projects and urbanization. They suggested about strong participatory sustainable management of these lakes by adopting sustainable harvest protocol, eco-restoration of Wetland areas and development of modern ago techniques. Jain et al. (2007) study about aquatic resources of Manipur Wetland reveals the threatened survival of aquatic resources and therefore, conservation of such resources was reported. Singh and Moirangleima (2009) studied the spatial distribution in two lakes, that is, Loktak and Pumlen from 1989 to 2002 and found the open water area of these two lakes have shrunk upto 50%. The main cause of shrinking these two lakes is by human pressure on it.

Other smaller lakes

Singh et al. (2010) study the water quality of Kharungpat located in Thoubal district with total area of 33.52 km^2. They found hyper-eutrophic status of the Lake mainly due to increased piscicultural activities being carried out by the people living in the vicinity of the lake along with rapid encroachments attributing to the deterioration of the water quality of this fresh water lake. And also they urged the need for immediate remedial measures to be taken up at a faster pace for protection and conservation of this degrading lake in order to save it from further deterioration and possible extinction. Singh and Moirangleima (2009) justified the reason for ignoring of other smaller lakes (Ikoppat/ Kharungpat, Waithoupat, Utrapat, Poiroupat, Sanapat, Loushipat and Ushoipokpipat) in analyzing the changes in open water area as all the smaller lakes are old, eutrophic, marshy and seasonal, that is, they remain flooded only during the rainy season and rest of the year they dry up and the land is used for agricultural purposes. Therefore, in literature we often witnessed all the Wetland related study is done based on major two lakes (Loktak and Pumlen) so far especially for spatial changes.

REASONS FOR WETLAND DEGRADATION

The major problems faced by the Wetlands in Manipur are (i) Siltation due to deforestation in hills thereby reducing the flood attenuation capacity of Wetlands (ii) Deterioration of water quality due to using of pesticides in agricultural activities in and around the Lake; and inflow of untreated sewage into the lake through the inflowing rivers leading to decline in water quality. These two problems are subject to act fast to stop further degradation and to save the future livelihood of the people. Due to the first problem, the sudden flash flood in the valley region and untimely drought are likely to increase in the future. The second problem will create changing the life cycle of aqua life and even death thereby reducing their numbers. People could no longer use water directly for domestic purposes or agricultural activities and overall disturbs the ecosystem of these Wetlands as well as to the daily normal life of the people. By understanding these major problems, efficient management of these Wetland are utmost demanded. The siltation problem could not stop 100% however; it can be reduced up to certain degree by preventing the vast deforestation in hills, giving awareness to the nearby people about losing of good services received from these Wetlands and make sure to understand about siltation scientifically and how to prevent them. Regularly removal of deposited soils and cleaning of these Wetlands will also be able to prevent flood results from decreasing depth of such Wetlands. Construction of small weir just at the entrance of such Wetlands will bring considerable solution to siltation problem. Using of pesticides, of course, increases the agricultural products but its several impacts on the ecosystem of Wetlands need to address timely reaching to every person. Using of pesticides can be reduced by introducing organic farming and the benefits of organic farming need to be accelerated by explaining about the health hazards caused by consuming foods comes from pesticides used farms. Proper disposal of sewage need to be implemented and effective operational use of sewage treatment plant is required. Local body with concern authority must join hands to implement the efficient management of Wetlands. It is evident that several government and non government organization are setup to take care of these Wetlands but the ideas and direction are mostly remains unknown to common people. There is lack of physical interaction between the concern authority and the people of the surrounding area and thereby no benefits can be achieved for year-long identification of problems about these Wetlands. Another problem faced is that people could not understand the scientifically written research findings, in this regard local non-governmental body need to help people understand easily. Due to Wetland ecosystem degradation while the population is increasing, people forced to practice the harmful fishing activities in the vicinity of the lake. Such practice can be reduced by improving their livelihood or giving them alternate livelihood opportunities/occupation like growing of mushrooms, bamboo plantation, establishment of separate fish farms, weaving cloths, etc.

CONCLUSION

The spatial distribution of Wetlands is decreasing so fast; open area have shrunk 50% as per Singh and Moirangleima (Sangsit, 2003) study from 1989 to 2002 in two major Lakes and only 15% to the total area of the state contributes as per latest ENVIS report (ENVIS, 2012). All studies were mainly based on ecological and socio-economic studies (Jain et al., 2011; Ngasepam et al., 2015; Jain et al., 2007; Ningthoujam et al., 2009; Rai and Raleng, 2011; Rai and Singh, 2014). It is also found that there is lack of educational/institutional scientific research as all studies were mainly carried out by Government set up organization like Loktak Development Authority; Directorate of Environment). The application of modern techniques such as Remote Sensing and Geographical Information system is quite less in the monitoring of Wetlands except few studies (Singh and Moirangleima, 2009; Rai and Singh, 2014). It is also witnessed that all the studies were mainly done about the largest lake, that is, Loktak Lake (Laishram and Dey, 2013) and second largest lake, that is, Pumlen Lake (Ngasepam et al., 2015) while the others smaller lakes were totally ignored. The spatial representation of changes occurring in and around the Wetlands is not done yet sufficiently which will otherwise help people understand more easily about the Wetlands status. Such changes were reported in numeric or long sentences in all the studies which are difficult to understand by the common people. Therefore, application of modern scientific techniques (such as RS and GIS) which displays the spatial changes in terms of figures, maps will help people understand quickly is required for effective solution to Wetland understanding.

Conflict of Interests

The authors have not declared any conflict of interests.

REFERENCES

Annual Administrative Report (2011-2012). Loktak Development Authority, Government of Manipur.

Annual Report (2008-2009). Central Pollution Control Board, Government of India.

Bassi N, Kumar MD, Sharma A, Saradhi PP (2014). Status of Wetlands in India: A review of extent, ecosystem benefits, threats and management strategies. J. Hydrol. Regional Stud. 2:1-9.

Brij G (1991). Biodiversity in Inland Aquatic Ecosystems in India: An Overview. Int. J. Ecol. Environ. Sci. 23:305-313.

ENVIS (2012). Centre, Directorate of Environment, Government of Manipur, 2012.

Finlayson CM, Spiers AG (1999). Global Review of Wetland Resources and Priorities for Wetland Inventory. CD-ROM, Supervising Scientist Report 144, Canberra, Australia, 1999.

Forest Department (2009). Government of Manipur "Keibul_Lamjao_National_Park". Retrieved on 8th June, 2016.

Ghermandi A, van den Bergh JCJM, Brander LM, Nunes PALD (2008). The Economic Value of Wetland Conservation and Creation: A Meta-Analysis, Working Paper 79, Fondazione Eni Enrico Mattei, Milan, Italy, 2008.

Haokip N (2007). Basine Delineation Map of Manipur, Profile on State of Environment Report of Manipur, 2006-07, Ministry of Environment and Forests, Manipur, 2007.

IPCC (2000). In N. Nakiaeenoviae (Ed). A special report of IPCC working group III: Summary for policymakers, emission scenarios. Cambridge: Cambridge University Press.

Jain A, Roshnibala S, Kanjilal PB, Singh RS, Singh HB (2007). Aquatic/semi-aquatic plants used in herbal remedies in the Wetlands of Manipur, Northeastern India. Indian J. Tradit. Know. 6(2):346-351.

Jain A, Sundriyal M, Roshinibala S, Kotoky R, Kanjilal PB, Singh HB, Sundriyal RC (2011). Dietary use and conservation concern of edible Wetland plants at indo-burma hotspot: a case study from northeast India. J. Ethnobiol. Ethnomed. pp. 7-29.

Laishram J, Dey M (2013). Socio-Economic condition of the communities dependent on Loktak Lake, Manipur: A study on five lakeshore villages. Int. J. Ecol. Environ. Sci. 39(2):87-96.

LDA, WISA (1998). Project Management Plan, Sustainable Development and Water Resource Management of Loktak Lake. Loktak Development Authority and Wetland International South Asia, 1998.

Lehner B, Doll P (2004). Development and validation of a global database of lakes, reservoirs and wetlands. J. Hydro. 296(1-4):1-22.

LiveMint-e Newspaper (2016). "Keibul Lamjao: The world's only floating national park" published on 8th July 2016.

Millennium Ecosystem Assessment (MEA) (2005). Ecosystems and Human Well-being: Synthesis, Island Press, Washington, DC, 2005.

Mitsch WJ, Nahlik A, Wolski P, Bernal B, Zhang LR (2009). Tropical Wetlands: seasonal hydrologic pulsing, carbon sequestration, and methane emissions. Wetlands Ecol. Manage. 18(5):573-586.

National Zoological Park (2016). Mathura Road, New Delhi, India "Sangai Deer (Cervus eldii eldii)", Retrieved on 16th July 2016.

Nationwide Wetland Mapping Project (1998). Space Application Centre, Ahmedabad, 1998.

Ngasepam RS, Devi LN, Singh CK, Shomendra M (2015). Socio-economic condition of the fishermen community of Pumlen Lake: A case study of Tokpaching village of Thoubal District, Manipur. Voice Res. 4(1):39-43.

Ningthoujam DS, Sanasam S, Nimaichand S (2009). Screening of Actinomycete Isolates from Niche Habitats in Manipur for Antibiotic Activity. Am. J. Biochem. Biotechnol. 5(4):221-225.

Prabhat KR, Singh MM (2014). Wetland Resources of Loktak Lake in Bishenpur District of Manipur, India: A Review. *Sci. Technol. J*. 2(1):98-103.

Rai PK, Singh MM (2014). Wetland Resources of Loktak Lake in Bishenpur District of Manipur, India: A Review. *Sci. Technol. J.* 2(1):98-103.

Rai SC, Raleng A (2011). Ecological Studies of Wetland Ecosystem in Manipur Valley from Management Perspectives, Ecosystems Biodiversity, PhD. Oscar Grillo (Ed.), 2011.

Ramsar Secretariat, Convention on Wetlands (Ramsar, Iran, 1971), 46th Meeting of the Standing Committee Gland, Switzerland, 8-12, 2013.

SACONH (2004). Inland Wetlands of India-Conservation Atlas. Salim Ali Centre for Ornithology and Natural History, Coimbatore, India; 2004.

Sangsit S (2003). Dancing Deer of Manipur. News Letter, Wild Life Institute of India, Volume 10, number 3. Archived from the original on 13 August 2005. Retrieved on 16th June, 2016.

Singh AL, Moirangleima K (2009). Shrinking water area in the Wetlands of the central valley of Manipur. Open Renew. Ener. J. 2:1-5.

Singh KK, Sharma BM, Usha Kh (2010). Ecology of Kharungpat Lake, Thoubal, Manipur, India: Part-I Water Quality Status. Ecoscan 4(2-3):241-245.

Technical report on Wetlands of Manipur (2012). Directorate of Environment, Government of Manipur, 2012.

The Hindu (2015). "Manipur to translocate critically endangered Sangai deer" published on 16th June, 2015

Turner RK, van der Bergh JCJM, Soderqvist T, Barendregt A, van der Straaten J, Maltby E, van Ierland EC (2000). Ecological economic analysis of Wetlands: scientific integration for management and policy. Ecol. Eco. 35(1):7-23.

Verma M (2001). Economic valuation of Bhoj wetlands for sustainable use, report for World Bank assistance to government of India. Management Capacity-Building. Bhopal: Indian Institute of Forest Management.

Wetland International South Asia (2005).

Wetlands in Manipur (1996). Reported by Fisheries Department, Government of Manipur.

Wikipedia (2016). "Keibul Lamjao National Park" Retrieved on 8th July, 2016.

academicJournals

Vol. 9(2), pp. 44-53, February 2017
DOI: 10.5897/IJWREE2016.0688
Article Number: C1ECF6162501
ISSN 2141-6613

http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Assessing the groundwater vulnerability in the upper aquifers of Zarqa River Basin, Jordan using DRASTIC, SINTACS and GOD methods

Alsharifa Hind Mohammad

Water, Energy and Environment Center, the University of Jordan, P.O. Amman 11942, 13139, Jordan.

Received 4 September, 2016; Accepted 27 October, 2016

Groundwater vulnerability is an overlay method that is used to determine the ability of pollutants to penetrate the aquifer and harming it. This method helps decision makers by highlighting expected areas to be polluted. In Jordan, groundwater is the main water resource the country uses to match its demand. The groundwater basins in Jordan are divided into 12 major basins; some are rechargeable and others are fossil. Many basins are over exploited; Amman Zarqa basin is a clear example for this case. In this study, a groundwater vulnerability map was produced for study area using SINTACS, GOD and DRASTIC indices to study the vulnerability of the aquifers throughout the targeted area. The different resulted maps show different vulnerability classes ranging from low to high reflecting the environmental, hydrological and hydrogeological settings of the groundwater and its recharge ability. The resulted map shows wide variation in groundwater vulnerability in different sites within the targeted area. Within the basin, areas with higher vulnerability are those with friable aquifer materials and shallow groundwater depths. Medium and low vulnerability classes exist too because of the variations of the environmental settings within the targeted areas.

Key words: Groundwater, vulnerability, SINTACS, DRASTIC, GOD, Zarqa River basin.

INTRODUCTION

Groundwater vulnerability is an overlay method that is used to determine the ability of pollutants to penetrate to the target aquifer and to harm it. This method helps decision makers by shedding light on pollution areas expected to pollute groundwater aquifers as caused by human activities on the ground surface.

The theory of groundwater vulnerability was first introduced in the 1960s in France to create an alertness of groundwater contamination (Vrba and Zaporozec, 1994). It can be defined as the possibility of percolation and diffusion of contaminants from the ground surface into the groundwater system. Vulnerability is usually considered as an ‘‘intrinsic’’ property of a groundwater system that depends on its sensitivity to human and/or natural impacts (Rahman, 2008). ‘‘Specific’’ or ‘‘integrated’’ vulnerability, on the other hand, combines

E-mail: s.jasem@ju.edu.jo.

intrinsic vulnerability with the risk of the groundwater being exposed to the loading of pollutants from certain sources (Vrba and Zaporozec, 1994). Groundwater vulnerability deals only with the hydrogeological setting and does not include pollutant attenuation. The natural hydrogeological factors affect the different pollutants in different ways depending on their interactions and chemical properties.

Many approaches have been developed to evaluate aquifer vulnerability. They include process-based methods, statistical methods, and overlay and index methods (Tesoriero et al., 1998). The process-based methods use simulation models to estimate the contaminant migration, but they are constrained by data shortage and computational difficulties (Babiker et al., 2005).

Different environmental parameters interfere when anticipating the amount and location of impurities that may affect the aquifers. Groundwater settings, hydrological and hydrogeological conditions, landuse parameters, environmental issues, soil parameters and other elements which may vary from one aquifer to other and from one area to another are used to assess the vulnerability of groundwater (Vrba and Zoporozec, 1994).

There are several groundwater pollution vulnerability evaluation systems, three methods or indices were applied within this work: SINTACS, GOD and DRASTIC. Among these models, the SINTACS method used in this study was developed by Civita (1990b, 1993, 1994) and Civita and De Maio (1997) to evaluate relative groundwater pollution vulnerability using seven hydrogeological parameters (Kuisi et al., 2006). It is a development of the US DRASTIC model adapted to Mediterranean conditions (Rahman, 2008). To evaluate the groundwater vulnerability for the study area, SINTACS model was preferred for different considerations, these include its suitability for application in Mediterranean regions (Civita, 1990a), its low cost depending on available datasets, and relative, dimensionless and non-measurable properties that depend on the aquifer characteristics as well as the characteristics of the wider geological and hydrological environment (Al-Amoush et al., 2010).

Zarqa River Basin is one of the most developed areas in Jordan (Figure 1), the expansion of Amman and other towns has been enormous, where before large areas of grazing land and fertile agricultural land could be found between Amman and other towns, it has now developed into one large urban conglomerate (Shatanawy, 2002).

Zarqa River basin is capable of supporting forests and agricultural activities. Natural forests occurring in the mountainous part are composed of oak, pine, juniper, wild olive and cypress. Agricultural activities and their associated weeds have supplanted the indigenous flora communities. Agriculture is scattered with the basin from rainfed orchards, olive and field crops to irrigated agriculture on the river banks and the Jordan valley. Private irrigated area using groundwater as a source of irrigation water can be found in scattered places in the middle and the eastern part of the basin. The main industrial activities in the basin are al-Hussein thermal power plant, the oil refinery, textile industries, paper processing, leather production, food Industries, distilleries, drugs and chemical industries, intermediate petrochemicals, engineering industries, paper and carton products, and mining industries (Phosphate). These activities are considered the main source of pollution to the surface and groundwater. In addition to that, the basin includes four municipal wastewater treatment plants whose effluent has reached 70 MCM/year and is discharged to the river. This volume is expected to reach 180 MCM by the year 2025 (Shatanawy, 2002). Groundwater represents the main source of water supply in the basin. Most of the groundwater exists in and is being extracted from the Basalt and Amman-Wadi Sir aquifers (Mohammad, 2016).

The main groundwater bodies are found in bedrock aquifers and they form the main groundwater sources. The main aquifers are composed of sandstone like Kurnub and Ram groups, the carbonate aquifers like Amman Silicified Limestone A7/B2 and Belqa B4/B5 group, in addition to the basalt aquifer. Within the targeted area, the most important aquifers are the B2A7 aquifer and the Kurnub sandstone aquifer systems (Figure 2).

ZRB is considered one of the most important groundwater basins in Jordan with respect to its groundwater resources. The safe yield of ZRB aquifer is about 87.5 MCM which makes about 32% of the country's renewable groundwater resources (MoE, 2012). The rock outcropping in the study area ranges in age from Creteaceous (Ajlun) to recent (Mcdonald and Partners, 1965). The succession from top to bottom is shown in Table 1.

Wadi Sir Formation A7 (Turonian)

It is the upper most unit of the Ajlun group. It outcrops extensively both in the north, central and south parts of the area. The massive crystalline limestone is karstic and weathered in the top 20 m of the formation. Below them there is a general increase in the marl chalky limestone and thin marl beds occur, indicating a transition into the underlying Shueib formation. The formation ranges in thickness between 50 and 250 m dipping to the east and northeast.

Amman formation B2 (Santonian_Campanian)

It is a cyclic deposit of chalk, phosphate, silicified phosphate, limestone and Chert. Its thickness ranges reaches 47 m in the study area.

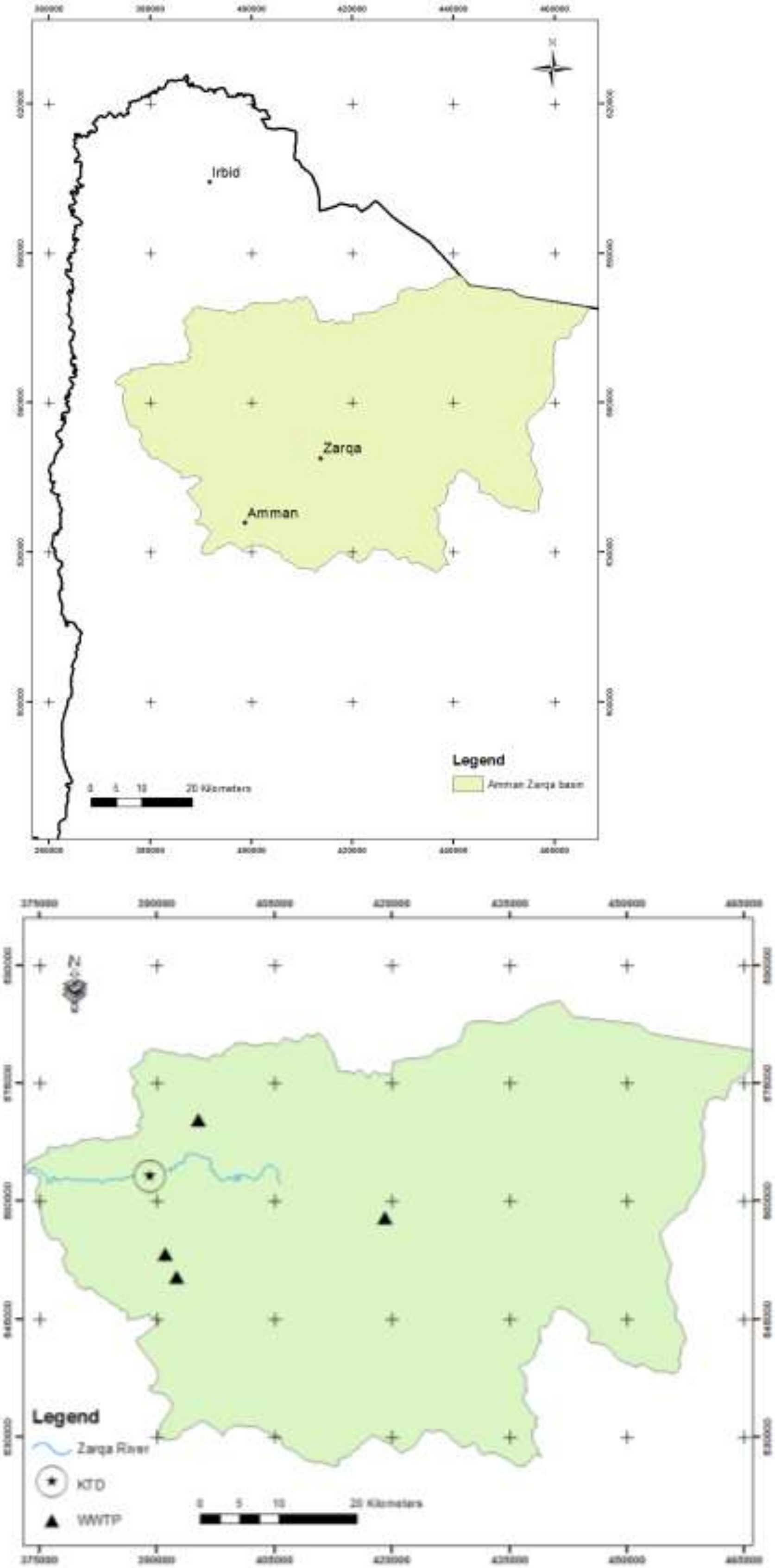

Figure 1. Location map for the study area.

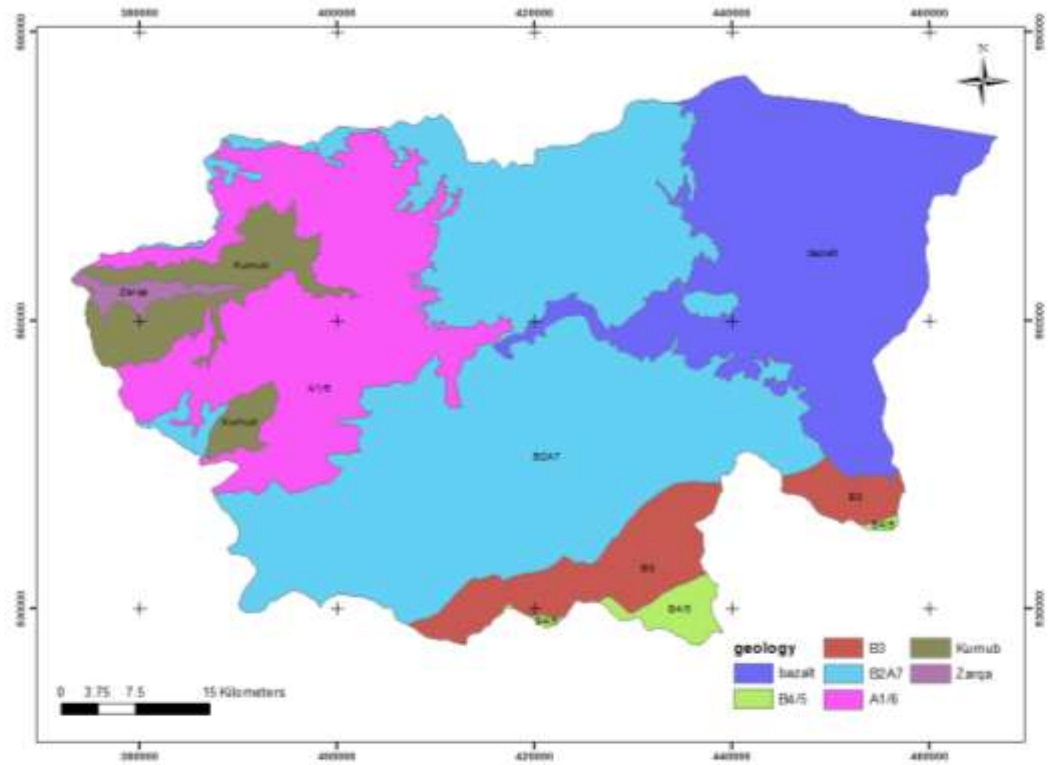

Figure 2. Hydrogeological distribution map for the study area.

Table 1. The outcropping of the basalt and B2/A7 formations (Mcdonald & Partners, 1965).

Group	Formation	Description
Recent	Recent Alluvium	River gravels and superficials gravels, silts
Basalt	Basalt	Scoriacous basalt, volcanic plugs
Balqa	B2 -Amman	Limestone, marl, massive chert.
Ajlun	A7- Wadi Sir	Crystalline and chalky limestone

The plateau basalt (Oligocene-Pleistocene)

Basalt outcrops in the northeastern part of the basin. Six major flows have been identified in the study area. Thin layers of clay and gravel consisting of limestone and Chert pebbles have been encountered between the successive flows. The basalt thickness in the northeastern part is 400 m and wedges to the west towards the periphery of the flows.

Younger alluvium formation

The younger alluvial consists of thin deposits overlying the basalt in the cemented out-wash and the old river terraces.

This study aims on assessment of the groundwater vulnerability of the Zarqa River basin upper aquifers using three different indices; this will help in protesting the groundwater in the targeted area from different pollution that might harm the aquifer system.

METHODOLOGY

The parametric models like SINTACS belong to the point count system model group in which every factor has not only its own score, but also an additional weight to reduce or amplify its importance during the analysis. The additional weight is set in relation to environmental characteristics, such as high dispersion phenomena from surface water bodies to groundwater or widespread pollution sources (Kuisi et al., 2006). The acronyms SINTACS stands for the seven parameters used in the model which are: water table depth (S), effective infiltration (I), unsaturated zone (N), soil media (T), aquifer media (A), hydraulic conductivity zone (C), topographic slope (S). The aforementioned seven parameters are used to define the hydrological setting of an area. These seven parameters are further sub-divided into ranges (or) zones, representing various hydrological settings and are assigned

Table 2. SINTACS Weight values (Civita and De Maio, 1997).

Component	Weight
Depth to water table	5
Infiltration rate	4
Unsaturated conditions	5
Soil texture	3
Aquifer hydrogeological characteristics	3
Aquifer permeability	3
Topographic slope	3

Table 3: GOD vulnerability index assessment.

GOD parameter	Range	Rating
		0.8
Depth to water table "m"	"5-10"	0.7
	"10-20"	0.6
	"20-50"	
Aquifer type	Unconfined	1
	Soil	0.4
	Alluvial, fine lime stone	0.5
Lithology	Sand, Igneous rock	0.6
	Sand and Gravel, sandstone, tuff	0.7
	Gravel	0.8
	caly	0.5
Soil media	clay- silt	0.6
	silt	0.8
	silt-sand	0.9

different rating in a scale of 1 in 10 based on the rating chart (Kuisi et al., 2006). The rating assigned to each of these ranges or zones indicate their relative importance within each parameter, in contributing to aquifer vulnerability. The seven parameters are themselves not considered to be equally important in vulnerability assessment.

The parametric models utilized belongs to the Point Count System Model (PCSM group) in which every factor has not only its own score, but also an additional weight in order to reduce or amplify its importance during the analysis. The additional weight is set in relation to environmental characteristics, such as high dispersion phenomena from surface water bodies to groundwater or spread pollution sources. The model used to predict aquifer vulnerability is SINTACS, developed by the National Research Council (Civita and De Maio, 1997).

The vulnerability index is given by rating seven parameters that is multiplied in each cell for the chosen weights string. In fact, one of the five described scenarios has to be identified and related string is assumed. According to this equation:

$$I\ SINTACS = \sum_{i=1}^{7} \mathrm{Pi} * \mathrm{Wi}$$

where Pi = score of each of the 7 parameters that the method considers, Wi = relative weight. Where Pi is the rating of each parameter and Wi is the weight of the chosen hydrogeological scenario. For every cell, it is given in such way a final score ranging from 26 to 260.

If we suggest the environmental impacts, there are normal impacts, then: Wi for each parameter is shown in Table 2.

GOD Index

This index is characterized by a rapid assessment of the aquifer vulnerability; it was developed by Foster in 1987 and 1998 (Ferreira and Oliveira, 2004) for studying the vulnerability of the aquifer against the vertical percolation of pollutants through the unsaturated zone, without considering their lateral migration in the saturated zone. Table 3 shows the GOD method. The approach used in this model takes in consideration three parameters: (1) Groundwater occurrence; (2) Overall aquifer class; (3) Depth table of the groundwater.

The GOD index which is used to evaluate and map the aquifer vulnerability caused by the pollution, was calculated by multiplication of the influence of the three parameters using the following equation:

GOD Index = Cl × Ca × Cd

Table 4. DRASTIC index method for assessing groundwater vulnerability (Aller et al., 1987).

Parameter	Range	Rating	Relative weighting
	0-2 m	7	
	2-5 m	6	
	5-9 m	5	
Depth to water (D)	9-15 m	4	5
	15-23 m	3	
	23-30 m	2	
	> 30 m	1	
	3	1	
	4	2	
	5	3	
Recharge by rainfall	6	4	4
	7	5	
	8	6	
	9	7	
	Massive shale	2	
	Metamorphic/igneous	3	
	Weathered met./igneous	4	
	Bedded sandstone, Limestone,	6	
	Shale sequences	6	
Aquifer media (A)	Massive sandstone	6	3
	Massive limestone	6	
	Sand and gravel	8	
	Basalt	9	
	Karst limestone	10	
	Soil thin or absent	10	
	Gravel	9	
	Sand	8	
	Peat	7	
	Shrinking and/or aggregated clay	4	
Soil media (S)	Sandy loam	5	2
	Loam Silty loam	4	
	Clay loam	3	
	Muck	2	
	Non-shrinking and non-aggregated clay	1	
	0-2%	7	
	2-6 %	6	
	6-10%	5	
Topography (T)	10-16%	3	1
	16-25%	2	
	>25%	1	
	Confining layer	1	
	Silt/Clay	3	
	Shale	3	
Impact of vadose zone	Limestone	6	5
	Sandstone	6	
	Bedded limestone, sandstone shale	6	

Table 4. Contd.

	Sand and gravel with significant silt & clay	6	
	Metamorphic /Igneous	4	
	Sand and gravel	8	
	Vesicular basalt	9	
	Karst limestone	10	
Hydraulic conductivity	$0.50×10^{-6}$ - $0.50×10^{-4}$	1	3
	$0.50×10^{-4}$ - $0.15×10^{-3}$	2	
	$0.15×10^{-3}$ - $0.36×10^{-3}$	4	
	$0.36×10^{-3}$ - $0.51×10^{-3}$	6	
	$0.51×10^{-3}$ - $0.10×10^{-2}$	8	
	> $0.10×10^{-2}$	10	

where Ca is the type of aquifer, Cl is the lithology of the unsaturated zone and Cd is the depth on the water surface. The GOD indexes are divided into five classes and vary between the extreme values ranging from 0 to 1.

DRASTIC Index

The DRASTIC index is one of the vulnerability indices that could be applied in Jordan, because of its applicability on climatic conditions, aquifer distribution and aquifer settings. In addition to that, the DRASTIC index has been selected according to its wide variation of parameters that really affect the groundwater system in any environment. In this model (DRASTIC), spatial datasets on depth to groundwater, recharge by rainfall, aquifer type, soil properties, topography, impact of the vadose zone and hydraulic conductivity of the aquifer are combined to assess the vulnerability of the aquifers to surface activities (Table 3) (Engel et al., 1996). The following equation governing DRASTIC index DI was defined by Knox et al. (1993), Fortin et al. (1997) and Fritch et al. (2000):

$$DI = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw$$

where DI is the DRASTIC Index, Dr is the rate of the D factor and Dw is the weight of the D factor, Rr is the rate for the recharge factor and Rw is the weight for the recharge factor, Ar is the rate for the aquifer media factor and the Aw is the weight to the aquifer media factor, Sr is the rate to the soil media factor and Sw is the weight to this factor, the Tr is the rate to the topography factor and the Tw is the weight to that factor, Ir is the rate of the impact of the vadose zone rate and Iw is the weight, and finally Cr is the rate for the hydraulic conductivity rate and Cw is the weight to this factor; this DRASTIC index in the equation is considered as an indicator for pollution potential (Table 4). The effect of different parameters on groundwater vulnerability has been described by Piscopo (2001).

For building the groundwater vulnerability map, different environmental parameters, which interfere while anticipating amount and location of impurities, that may affect the aquifers, were taken into consideration. Groundwater settings, hydrological and hydro-geological conditions, land use parameters, environmental issues, soil parameters and other elements, which may vary from one aquifer to another and from one area to another were used to determine the vulnerability of groundwater (Vrba and Zaporozec, 1994). The different spatial parameters of the aquifer as obtained (geology, recharge, water table, soil texture, etc.) were exported into GIS and the equation for calculating groundwater vulnerability with DRASTIC Index were used to deduce different vulnerability classes.

RESULTS AND DISCUSSION

The resulted map of SINTACS index is as shown in Figure 3. This shows that the B2A7 aquifer has 2 vulnerability classes, the very low and low classes which reflect the safe situation of ground water; meanwhile, the Kurnub aquifer reflects four vulnerability classes ranging from very low to moderately high vulnerability.

While the GOD index can be divided into five categories: negligible (0-0.1), low (0.1-0.3), moderate (0.3-0.5), high (0.5-0.7), and very high (0.7-1) (Foster et al., 2002); then the vulnerability classes within the targeted area are as shown in the Figure 4 with 3 vulnerability classes ranging from negligible to high vulnerability class.

Also, the resulted map of DRASTIC index is as shown in Figure 5. This shows that the B2 A7 aquifer has 2 vulnerability classes, the very low and low classes which reflects the safe situation of ground water; meanwhile, the Kurnub aquifer reflects four vulnerability classes ranging from very low to high vulnerability, it is very clear that the lower water table are the areas with higher risks. It cannot be noticed that DI and SI results are compatible to each other, because of the high similarity of the environmental conditions that are taken into consideration during application of the two indices.

As shown in Figure 6, it could be noticed that both DRASTIC and GOD vulnerability indices used within this work are very compatible to each others and shows mostly the same high and low risk areas within the targeted area; areas cover by B2A7 aquifers are with low to medium vulnerability classes for all indices, and as shown from different resulted map the high and very vulnerability classes in all indices are coming with Kurnub aquifer which is because of the aquifer media "sandstone" which reflects higher vulnerability potentiality. In the meanwhile, SINTACS vulnerability map shows much variability of classes and this comes from the detailed of this index in the S factor or depth to water table which started by very small intervals.

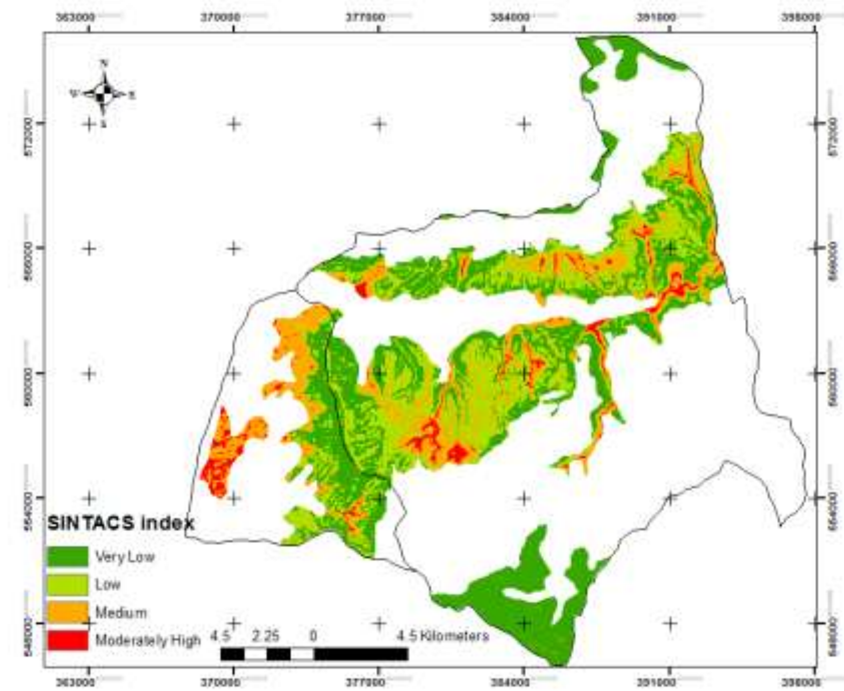

Figure 3. SI index for the aquifers within the study area.

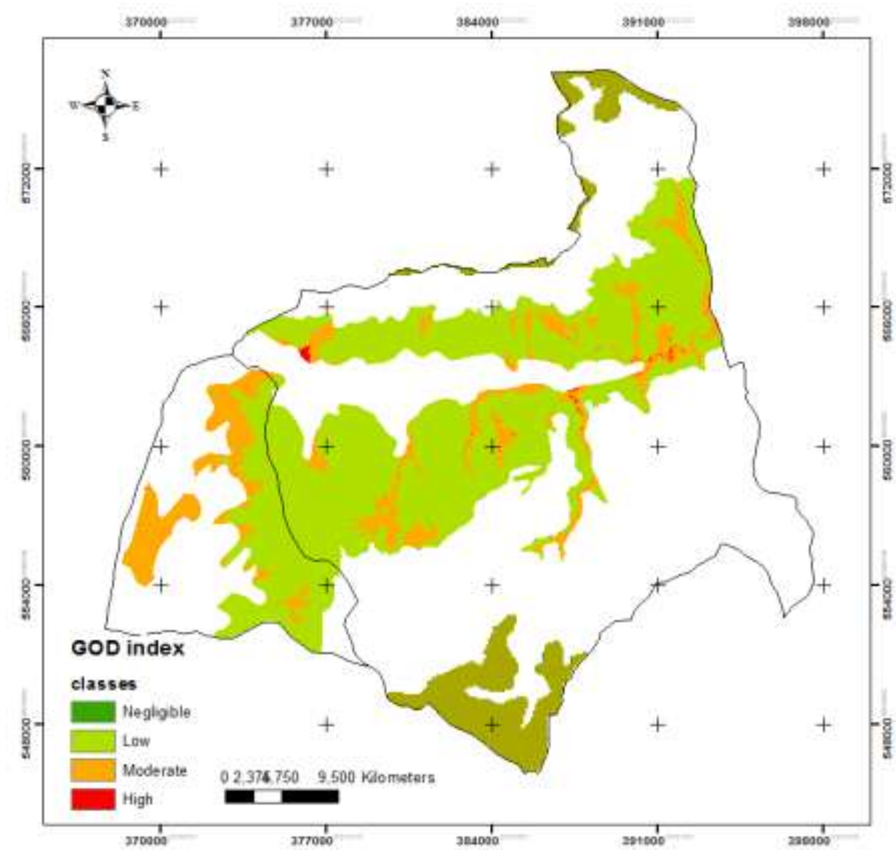

Figure 4. GOD index for the aquifers within the study area.

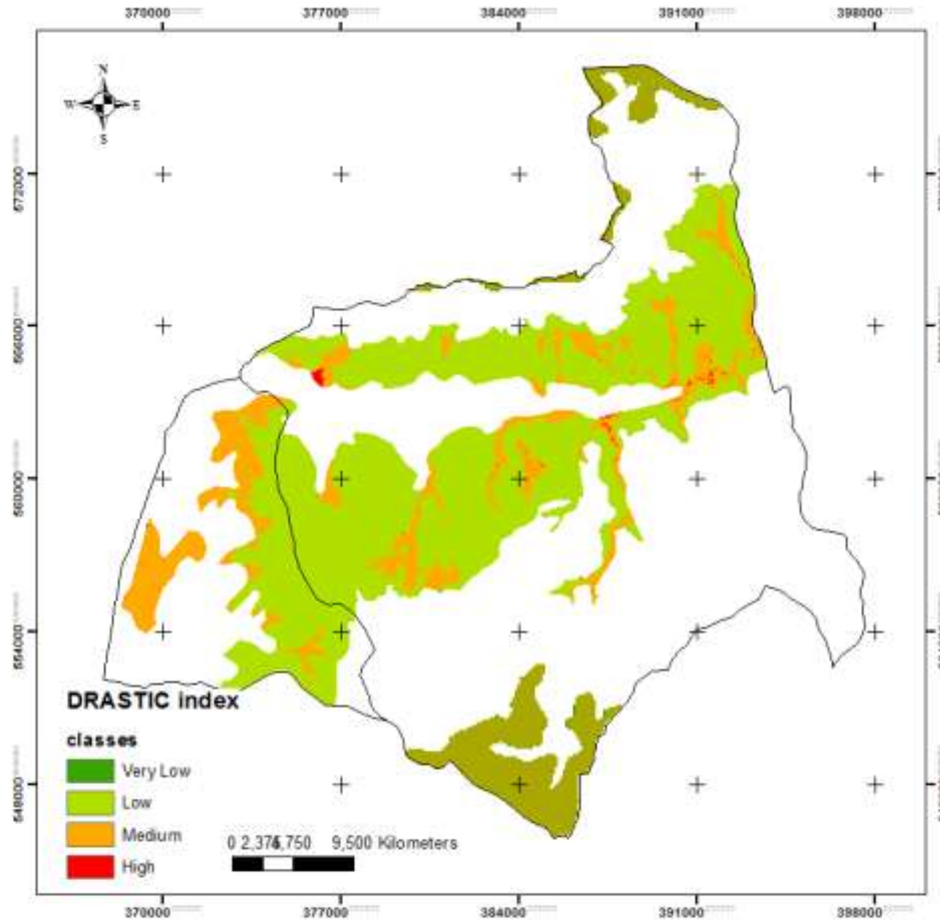

Figure 5. DRASTIC index for the aquifers within the study area.

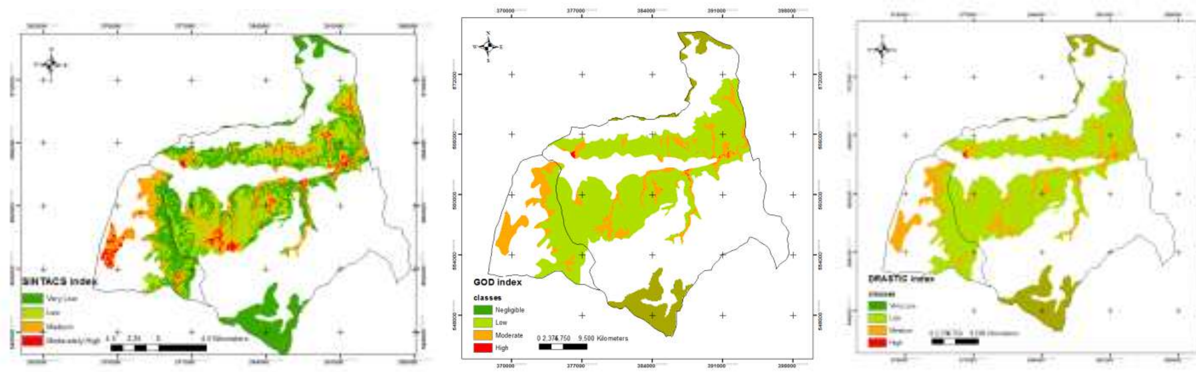

Figure 6. Comparison between the 3 indices for the aquifers within the study area.

Conclusion

As a conclusion, this paper concludes that most of the targeted aquifers within the study area are with low to very low vulnerability class, but this does not mean that the water situation is not threatened. The high and medium vulnerability classes exists too, however, any activity to take place within the outcropped aquifer will affect the groundwater resources there and then to study an effective assessment to any action to be done.

Among the three applied methods, SINTACS method is the best to be applied because of its more detailed in showing the vulnerability classes and its variety in description aquifers like GOD method which is a resulted more for Karst aquifer.

Conflict of Interests

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This paper was one of the results of the funded project: Studying the effects of using the effluent of King Talal dam water in irrigation on soils and groundwater in evaluating of groundwater vulnerability maps for the area, funded by Scientific Research Support Fund "SRF", Ministry of Higher Education, Jordan, in the period of December 2014-June 2016.

REFERENCES

Al-Amoush H, Hammouri NA, Zunic F, Salameh E (2010). Intrinsic vulnerability assessment for the alluvial aquifer in the northern part of Jordan valley. Water Resour. Manage. 24:3461–3485.

Aller L, Bennett T, Lehr JH, Petty RJ, Hackett G (1987). DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeological settings. U.S. Environ. Prot. Agency EPA/600/ 2-87/036, 622 p.

Babiker IS, Mohamed AAM, Tetsuya H, Kikuo K (2005). A GIS-based DRASTIC model for assessing aquifer vulnerability in Kakamigahara Heights, Gifu Prefecture, central Japan. Sci. Total Environ. 345:127–140.

Civita M (1990a). La valutacione della vulnerabilitia degli aquifer all'inquinamamento. In Proceedings of 1st con. naz. protezione egestione delle aque sotterranee: metodologie, technologie e obiettivi, 20–22 September, Maranosul Panaro pp. 39–86.

Civita M (1990b). Legenda unificata per le Carte della vulnerabilita' dei corpi idrici sotterranei/Unified legend for the aquifer pollution vulnerability Maps. Studi sulla Vulnerabilita' degli Acquiferi, 1 (Append.), Pitagora Editrice, Bologna, pp. 13.

Civita M (1993). Groundwater vulnerability maps: a review. In Proceedings of the IX symposium on pesticide chemistry ''mobility and degradation of xenobiotics'', 11–13 October, Piacenza (Italy: Edizioni G. Biagini) pp. 587–631.

Civita M (1994). Le Carte della vulnerabilita' degli acquiferi all'inquinamento. Teoria and Pratica. Pitagora Editrice, Bologna, pp. 325.

Civita M, De Maio M (1997). SINTACS. Un sistema parametrico per la valutazione e la cartografia della vulnerabilita' degli acquiferi all'inquinamento. Metodologia and Automatizzazione, Pitagora Editrice, Bologna, 60.

Engel BA, Navulur K, Cooper B, Hahn L (1996). Estimating groundwater vulnerability to non-point source pollution from nitrates and pesticides on a regional scale. In pp. 521-526 (IAHSPublication No. 235).

Ferreira JPL, Oliveira MM (2004). Groundwater vulnerability assessment in Portugal. Geofísica Int. 43(4):541-550.

Fortin M, Thomson KPB, Edwards G (1997). The role of error propagation for integrating multisource data within spatial models: the case of the DRASTIC groundwater vulnerability model. Earth Surf. Rem. Sens. Proc. SPIE conf. London pp. 358-361.

Foster S, Hirata R, Gomes DD, Elia M, Paris M (2002). Protecção da qualidade da água subterrânea: um guia para empresas de abastecimento de água, órgãos municipais e agências ambientais, São Paulo, Grupo Assessor em Gestão de Águas Subterrâneas do Banco Mundial, Banco Mundial – Banco Internacional de Reconstrução e Desenvolvimento, 2006. Tradução de Groundwater Quality Protection: A Guide for Water Service Companies, Municipal Authorities and Environment Agencies, Washington, Groundwater Management Advisory Team, The World Bank – The International Bank for Reconstruction and Development.

Fritch TG, McKnight CL, Yelderman JC, Arnold AL (2000). An aquifer vulnerability assessment of the Paluxy aquifer, central Texas, USA, using GIS and a modified DRASTIC approach. Environ. Manage. 25:337-345.

Knox RC, Sabatini DA, Canter LW (1993). Subsurface transport and fate processes, Lewis Publishers, USA.

Kuisi MA, El-Naqa A, Hammouri N (2006). Vulnerability mapping of shallow groundwater aquifer using SINTACS model in the Jordan Valley area, Jordan. Environ. Geol. 50:645–650.

McDonald Sir M, Partners in corporation with Hunting Geological Surveys limited (1965). East Bank water resources, London, Amman. Vol. 6.

MoE (2012). Climate change adaptation in Zarqa River basin, Assessment of direct and indirect impacts of climate change scenarios. Water resources study, Vol. 1, UNDP.

Mohammad AH (2016). A modified modeling of potentiality and vulnerability of the groundwater resources in Amman Zarqa Basin, Jordan. Kuwait J. Sci. 43(1):208-221.

Piscopo G (2001). Groundwater vulnerability map, explanatory notes, Castlereagh Catchment, NSW Department of Land and Water Conservation, Australia.

Rahman A (2008). A GIS based DRASTIC model for assessing groundwater vulnerability in shallow aquifer in Aligarh, India. Appl. Geogr. 28:32-53.

Shatanawy MR (2002). Policy Analysis of Water, Food Security and Agriculture Policies In Jordan, Review paper submitted to the World Bank.

Tesoriero AJ, Inkpen EL, Voss FD (1998). Assessing ground-water vulnerability using logistic regression. In Proceedings for the Source Water Assessment and Protection 98 Conference, 28-30 April, Dallas, TX (Virginia: NAWQA Publications) pp. 157-165.

Vrba J, Zoporozec A (eds.) (1994). Guide book on Mapping Groundwater Vulnerability. International Contributions to Hydrogeology (IAH) Hannover 16:131.

International Journal of Water Resources and Environmental Engineering

Related Journals Published by Academic Journals

- *International Journal of Computer Engineering Research*
- *Journal of Chemical Engineering and Materials Science*
- *Journal of Civil Engineering and Construction Technology*
- *Journal of Electrical and Electronics Engineering Research*
- *Journal of Engineering and Computer Innovations*
- *Journal of Engineering and Technology Research*
- *Journal of Mechanical Engineering Research*
- *Journal of Petroleum and Gas Engineering*

academicJournals