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Review

Impacts of climate change on groundwater resources in Vietnam: a short review

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ABSTRACT

Groundwater is a vital resource for climate-change adaption in Vietnam. Yet, groundwater resource is also affected by climate change and the impacts have just received more concern in recent years. In spite of that, various studies have conducted to evaluate the impacts of climate change on groundwater resources in Vietnam. The studies have been performed from the North (Ha Noi and Nam Dinh) to the Central (Binh Dinh, Serapok watershed, and Thanh Hoa) and the South of Vietnam (Ho Chi Minh city, Ba Ria – Vung Tau, and Mekong Delta). Hydroglical and groundwater models are powerful tools applied for those studies. Besides, the change of rainfall, sea level rise, and urbanization are main factors, which are projected in different climate change scenarios for assessing the impacts; groundwater recharge, groundwater level, and groudwater quality are common components of groundwater resources, which are evaluated for the impacts of climate change. Based on the evaluation of such climate factors on groundwater components, many meaningful conclusions have been declared. This paper summarizes the results of recent studies on the impacts of climate change on groundwater resources with respect to various scenarios in Vietnam. Up-to-date studies mostly indicated the negative impacts that climate change will decrease the groundwater recharge and fresh groundwater availability or increase groundwater salinization, mainly in the coastal areas. The principal reasons are changes in rainfall, land-use change derived from climate change, and sea-level rise. Those studies have delivered valuable information for groundwater management and climate-change adaption strategies in Vietnam. Despite the variety of different research, there are still knowledge gaps of climate change – groundwater interaction e.g., indirect effects of climate change derived from increasing of groundwater abstraction and/or intensive agricultural practices in the future. Those issues are potential topics for future research.

Key words: Climate change, groundwater, groundwater recharge, sea-level rise

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INTRODUCTION

In recent years, climate change has caused serious impacts around the World, and Vietnam is not excluded. According to the Global Climate Risk Index 2021[1], which reflects the direct losses and fatalities of extreme weather events, Vietnam is ranked at 13th among the countries most impacted by climate change in the period 2000 – 2019. In addition, other natural resources are also affected, especially water resources. In Vietnam, surface water is the main resource for water supply but it is vulnerable to climate change. Many studies on potential impacts of climate change have focused on the surface water to project the change of river flow[2–5], seawater intrusion in coastal delta[6,7], water quality[8,9], flood frequency[10]. Most of those studies indicate the negative effects responding to different climate change scenarios such as increase of streamflow in rainy season and more drought in dry season, declination of water quality and deeper inland saltwater intrusion. On the other hand, groundwater is also an important water supply source for the adaption to global environment changes. More abstraction wells have recently been installed[11,12] for water demand and, thus, various issues have occurred such as groundwater level declination, seawater intrusion[13], land subsidence[14,15], and arsenic contamination[16,17]. Various research was performed to identify and verify the influence of geological conditions and human activities on the groundwater system in Vietnam[18]. Since groundwater is a part of the hydrological cycle, any changes in climate would affect groundwater resources. However, research on the impacts of climate change on groundwater was very little, even in the World[19,20]. This limitation may relate to difficulties in characterizing the hydrogeology below the surface and the slow response to climate variability. In spite of the difficulties, the issue has been more concerned in recent years. This paper will give a short review of recent research on the impacts of climate change on groundwater resources. The skeleton of the paper consists of three main parts: (i) Climate change scenarios in

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Vietnam (ii) Impacts of climate change on groundwater (ii) Remarkable considerations. This review paper delivers recent knowledge of groundwater-climate change issues to support authorities in planning and developing adaptation strategies for climate change.

STUDY AREA

Vietnam locates in Southeast Asia and shares terrestrial border with China in the North (1,281 km), Laos (2,130 km) and Cambodia (1,228 km) in the West (Figure 1). The land area of Vietnam is about 320, 000 km^2 with a coastline of 3,289 km. Most of Vietnam is covered by hilly and mountainous areas (Figure 1) with the elevation between 100 and 3400 m. There are 16 major River basins in Vietnam and the two the two largest basins are Red River in the North and Mekong in the South.

Vietnam's climate is mainly characterized by tropical monsoon zone and varies from the North to the South. In the North mountainous region, the lowest temperature is observed from 10^{o}C to 16^{o}C and from 25 ^{o}C to 30 ^{o}C in the South region. In summer, the average temperature ranges from 25 ^{o}C to 30 ^{o}C. the annual rainfall shows a wide range in Vietnam, which is from 600 mm to 5000 mm, mostly from 1,400 mm to 2,400 mm. The total of rainfall accumulates about 80-90% in rainy season.

In Vietnam there are six major hydrogeological regions which are Eastern North, Western North, plain of the North, Northern Central, Southern Central, and Plain of the South[21]. The aquifers in the regions are mainly formed form uncosolidated materials, fracture-pore basalt, carbonate, sandstone, and fracture of instrusive rock. The hydrogeological regions contain a large amount of groundwater for water supply. In the plain of the North, the groundwter reserves is up to 22.5 million m^3/day and 18.5 million m^3/day in the Highland of Central Vietnam. In the Plain of South, the static reserve of groundwater in the plain of the South is estimated about 22.7 million m^3/day and the natural dynamic reserve is 4 million m^3/day. The natural dynamic reserve, here, is considered as the amount of groundwter that can be sustainably abstracted for a long period. The dynamic reverse sources come from recharge (infiltration from rainfall and river) and natural flow through transboudaries. In plain of the Southern Vietnam, infiltration from rainfall contribute up to 95% of natural dynamic reserve[21]. It means that the change of rainfall can immediately impact on groundwater resources. In other words, the impact of climate change on groundwater resources is obvious in Vietnam.

METHODOLOGY

In this review paper, Google Scholar is used to search papers related to our target. The searching keywords are "groundwater" + "Climate change" + "Vietnam". Only papers published from 2015 are considered in this paper. The totality of reviewed papers is 14.

CLIMATE CHANGE SCENARIOS IN VIETNAM

Climate change refers to the shift of average of the climate in a period due to natural processes (earthquake, volcano eruptions, solar irradiance and orbital changes) and human activities (increase greenhouse gases (GHGs) emission). Climate change is indicated by the alternation of various factors such as temperature, precipitation, and sea level). Since the mean global temperature was recorded in 1850, it increased 1.2 $\pm$ 0.1 ^{o}C in 2020[22]. In the period 1901-2010, global mean sea level rose by 0.19 m. Meanwhile, GHGs largely increased since the start of the industrial era in 1750. Specifically, CO_2, CH_4, and N_2O increased, respectively, 40%, 150%, and 20% relative to 2011[23].

In Vietnam, an observation of temperature from 1971 to 2010 showed an increasing rate of 0.26 $\pm$ 0.10 ^{o}C per decade[24]. The data from Ministry of Natural Resources and Environment[24] indicate that annual rainfall decreased in the north and increased in the south (1958 – 2014), while sea level rises around 3.34 mm/year. The satellite data in the period of 1993-2014 showed that mean sea level in at Vietnam's coastal increased 3.5 mm/year in the period 1993-2014. Those observations are utilized for analyzing the trend of climate variables in the past and supporting the conduction of climate change scenarios in Vietnam. The methodology for construction climate change in Vietnam is simplified in Figure 2. The climate change scenarios for Vietnam are corresponding to The Representative Concentration Pathways (RPCs). RCPs describe four different 21^{st} century pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use[23]. The values after RCP (e.g., 4.5 or 8, Table 1) refer to radiative forcing in Watt/m^2 by the end of 2100 compared to the preindustrial era. Each RCP leads to a warming temperature at the end of 21^{st} century (Table 1). As a result, a summary of climate change projections for Vietnam is shown in Table 2. Those results are references for researchers to study the impacts of climate change on groundwater in Vietnam.

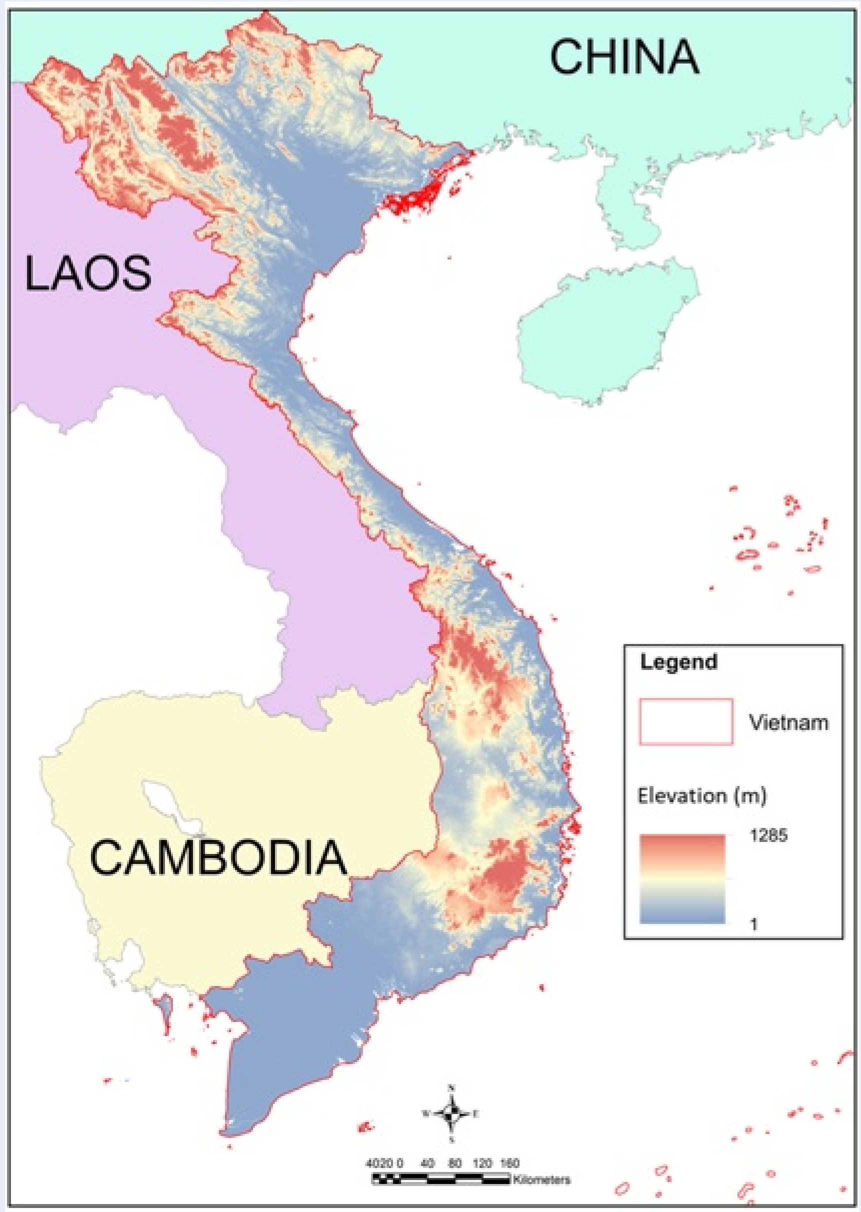

Figure 1: Location of Vietnam.

Table 1: RCP for climate change scenarios.

RCP	Radiative forcing (W/m^2)	Mean warming temperature in 2100	Emission trend	Equivalent to Special Report on Emissions Scenarios [25]
1.9	1.9	1.5	Very strongly declining emissions	No equivalent
2.6	2.6	2	Strongly declining emissions	No equivalent
4.5	4.5	2.4	Slowly declining emissions	B1
6.0	6.0	2.8	Stabilising declining emissions	B2
8.5	8.5	4.3	Rising emissions	A2/A1FI

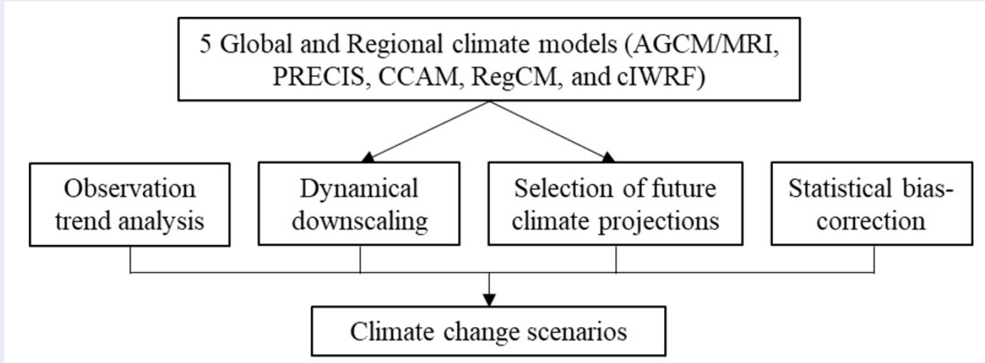

Figure 2: Simplified scheme for Climate change scenarios in Vietnam

Table 2: Changes of climate variables for different Climate change scenarios for Vietnam (Modified from [26]).

Climate variable*	RCP4.5			RCP8.5		
	2016-2035	2046-2065	2080-2099	2016-2035	2046-2065	2080-2099
Mean annual temperature (^oC)	0.7	1.5	2	0.9	2	3.6
Mean annual rainfall (%)	11.3	15	18.5	9.9	16	21
Mean sea-level rise for East Sea (cm)	13	29	49	13	34	64
Mean sea-level rise for coastal areas and island (cm)	13	28	46	13	33	64

** The future change of climate variables is compared to the mean value of the baseline period (1986-2005).*

IMPACTS OF CLIMATE CHANGE ON GROUNDWATER SYSTEM

As a part of the hydrological cycle, groundwater can be directly and indirectly affected by climate change. Groundwater recharge and groundwater-surface water interaction are directly affected by the change of rainfall. While changes in land use and water demand, which are induced by climate change, indirectly influence groundwater quantity and quality. The studies on those impacts are summarized in Table 3.

Table 3: Summary of recent studies for the impacts of climate change on groundwater resources in Vietnam.

Study	Year/Journal type	Ref.	Location	Hydrological model	Climate change scenario	Impacts on groundwater
Ha and Sucharit	2015 (Conference)	[27]	Ho Chi Minh City	MODFLOW [a]	Rainfall will decrease 7% in the 2030s; and increase 23% in the 2090s Temperature at the end of this century will increase to 3.5^{o}C; Evapotranspiration is expected to increase by 16% in the 2090s.	Groundwater recharge decreases 29% in 2030s), increases 51% in 2070s) and 23% in 2090s.
Shrestha et al.	2018 (Peer-reviewed)	[28]	Ho Chi Minh City	SWAT [b]	RCP4.5 and RCP8.5	Groundwater recharge decreases 13.8 - 14.4%.
Lam et al.	2021 (SCI)	[29]	Thi Vai area	PANTA RHEI–FEFLOW [c]	RCP8.5	Groundwater recharge decreases 2.6% and 10.9%, respectively in rainy and dry season. Groundwater level declines up to 20.2 m.
Tam et al.	2016 (SCI)	[30]	Central Vietnam	WetSpass [d], MODFLOW, SEAWAT [e]	A1	Both groundwater recharge (about 10%) and groundwater level decrease.
Schmidt et al.	2015 (Book chapter)	[31]	South of Vietnam	NA [f]	NA	Declination of groundwater level in dry season due to the decrease of river flow.
Vu at el.	2018 (SCI)	[32]	Binh Dinh	VS2DH [g]	NA	Increase of groundwater discharge to rivers.
Huyen et al.	2017 (SCI)	[33]	Serapok watershed	SWAT	A1B and A2	Groundwater discharge contributes to river flow over 30%.
Adhikari et al.	2020 (SCI)	[34]	Ho Chi Minh City	SWAT	Projecting rainfall and temperature based on Regional Circulation Model	Groundwater recharge increases in low urbanization scenarios but decreases in medium and high urbanization scenarios.
Pham et al.	2019 (SCI)	[35]	Mekong Delta	SEAWAT	Change of Paleoclimate over past 60 ka	Declination of fresh groundwater
Schmidt et al.	2015 (Book chapter)	[36]	Thanh Hoa	SEAWAT	A1FI, B2	Groundwater level decreases, and salinization increases
Schmidt et al.	2015 (Book chapter)	[37]	Ba Ria - Vung Tau	SEAWAT	A1FI, B2	Salinization increases; recharge from precipitation increases
Pham and Lee	2015 (SCI-E)	[12]	Nam Dinh	SEAWAT		Minor effect of sea-level rise on salinization

[a] Modular Three-Dimensional Finite-Difference Groundwater Flow Model; [b] Soil and Water Assessment Tool; [c] Finite Element subsurface FLOW system; [d] Water and Energy Transfer between Soil, Plants and Atmosphere under quasi-Steady State; [e] a three-dimensional variable-density groundwater flow and transport model; [f] not available; [g] a variably saturated two-dimensional groundwater flow model.

Recharge

Groundwater recharge can come from various sources such as precipitation, seeping from rivers/lakes, return flow from agricultural practices, and municipal water supply[38,39]. Of those sources, precipitation mostly contributes a large amount of replenished water to the aquifer system. In Vietnam, groundwater recharge varies from areas. In Day River basin, the groundwater recharge ranges from 37 to 601 mm/year, averagely 248 mm/year[40]. In Phan Rang area, a field experiment by Vinh *et al.*[41] indicated a recharge rate of 311 mm/year in the period 2012-2013. In Dak Lak Plateau, the average groundwater recharge is 431 mm/year[42]. In Hanoi, groundwater recharge was estimated at about 20% of rainfall (340 mm/year;[43]). However, in Mekong Delta, although the rainfall is relatively high (about 1,900 mm/year,[44]), groundwater recharge from precipitation is limited (mostly <20 mm/year,[27]). Most of those studies showed the direct effect of rainfall on groundwater recharge, and thus, each climate change scenario will differently impact on groundwater recharge. Ha and Sucharit[28] projected rainfall and groundwater in Ho Chi Minh city using a scenario for the increasing temperature of 3.5 ^{o}C in 2100. The results showed a similar trend of rainfall and groundwater recharge at the end of the 21st century, which respectively increases 23% and 23%. Another research by Shrestha *et al.*[29] used rainfall trend based on RCP 4.5 and RCP8.5, yet the groundwater recharge is projected to decrease by 13.8% and 14.4%, respectively, different from Ha and Sucharit[28]. The differences may relate to the models applied for the estimation of recharge. Ha and Sucharit[28] projected the recharge based on the discrepancy of monthly rainfall and evapotranspiration and soil type zones in Ho Chi Minh city and vicinity areas. Then, the projected recharge is assigned in a calibrated groundwater flow model (MODFLOW) for simulating the future recharge in Ho Chi Minh City. While, Shrestha *et al.*[29] predicted future recharge using SWAT (Soil and Water Assessment Tool) model, a hydrological model, which requires more climatic data such as solar radiation, wind speed, air temperature, and relative humidity. Not far from Ho Chi Minh city, climate change is projected for assessing the effects on groundwater system in Thi Vai area with respect to RCP8.5[30]. The results indicated the decrease of groundwater recharge (up to 10.9% in dry season), and strong declination of groundwater level in deep aquifer (up to 20.2 m). In Central Vietnam, the groundwater recharge is also predicted to be decreased in the Central Vietnam. For scenario A1B in the 2050s, groundwater recharge decreases 11% for Holocene aquifer 10% for Pleistocene aquifer[31].

Overall, groundwater recharge is mostly projected to decrease while the future rainfall is predicted to increase at the end of 2100 in climate change scenarios in Vietnam[26]. The similarity is also observed in tropical climate countries such as Thailand[32] and Ivory Coast[33]. This trend may relate to the less precipitation in the dry season projected in the selection of Regional Climate Models (RCMs). The hydrogeological condition of study areas is another reason as it affects the infiltration rate of precipitation into aquifers.

In addition, the projected groundwater recharge did not distinguish the contribution of other recharge sources from rainfall e.g., recharge/discharge from/to surface water. In another word, the groundwater-surface water interaction responding to climate change also affects groundwater recharge. For this case, Schmidt *et al.*[34] addressed a relation between flow of rivers and groundwater level with a decrease of 15-20% and 11 m, respectively, for the south of Vietnam. Locally, groundwater is also recharged from rivers in rainy season or storm events and discharge to dry season in Binh Dinh[45]. While groundwater discharge to surface water, which is estimated for scenarios A1B and A2, contributes up to 30% of the total flow into Serapok watershed[46]. This means that the discharge to surface water can alter the total groundwater recharge projected in climate change scenarios. Furthermore, land-use change induced by climate change also indirectly modifies groundwater recharge. In the low urbanization scenarios considering climate change in Ho Chi Minh City, groundwater recharge increases up to 15% in the period 2076-2100[47], this is in an agreement with the result of Ha and Sucharit[28]. Yet, the groundwater recharge shows a reduction of 30% and 52% for medium and high urbanization scenarios, respectively[47]. This means that the increase of impermeable surface derived from urbanization will limit the infiltration of rainfall to aquifer system.

Impact of Sea level rise on groundwater salinization

Since Vietnam has a coastline with a length of about[35], the effects of sea-level rise derived from climate change is a major issue for water resources management. An assessment of sea-level rise due to climate change in Mekong Delta (Vietnam) showed that saltwater will intrude up to 50 – 60 km inland according to the sea level rise of 30 cm in RCP6.0[7]. As a result, approximately 30,000 ha of agricultural area will be affected by salinity. Other studies also predict that saltwater will intrude far inland due to sea-level rise concerning different climate change scenarios. For instance, saltwater with a salinity of 4% intrudes up to 20 km on Thu Bon-Vu Gia River in RCP8.5[36] and up to 41 km in Red River Delta (RCP8.5,[37]).

Considering the relation of the change of sea level over the past sixty thousand years with the present distribution of fresh-saline groundwater in Mekong Delta, Pham *et al.*[48] indicated that sea-level changes are one of the important factors that affected the availability of fresh groundwater. The study also strongly suggested the declination of fresh groundwater under natural conditions (e.g., sea-level rise) since the lowstand of mean sea level in Mekong Delta. It means that the impact of sea-level rise on groundwater resource is obvious and predicted to be more serious corresponding to recent climate change scenarios. Since sea level rise causes the salinization of surface water as well as groundwater through infiltration, groundwater quality can be unusable for human use. Sea level rise also increases the landward hydraulic gradient of seawater and, thus, accelerates seawater intrusion in coastal aquifer. Therefore, the influence of sea-level rise on groundwater resources is necessarily taken into account.

Recent studies on this issue mostly proposed that salinization will increase in Thanh Hoa[49] and Ba Ria-Vung Tau[50] in different climate change scenarios. While Pham and Lee[12] mentioned that the impact of sea-level rise on groundwater salinization is quite small in Nam Dinh Province, groundwater abstraction is the main factor. In addition, dry season is forecasted to be longer and, thus, groundwater is the only source for water supply when most of the surface water bodies are salinized in coastal areas during this period. This means that more groundwater will be abstracted during dry season and the declination of groundwater level is exacerbated. As a result, salinization in groundwater system will be more serious in the future.

The impact of sea level rise on groundwater salinization is also a worldwide issue. Research by Jasechko *et al.*[51] showed that more than 15% of contiguous coastline in United States are potential seawater intrusion in coastal aquifers and sea level rise is one of threats to the issue. Furthermore, several models investigating the impacts of sea level rise on seawater intrusion in coastal regions had indicated the threat of salinization to fresh groundwater[52,53]. Therefore, research on this issue needs to be more considered for climate change adaptation measures in Vietnam.

REMARKABLE CONSIDERATIONS

Overall, there have been several studies on the impacts of climate change on groundwater resources in Vietnam since 2015. Most of the studies focus on the impacts on groundwater recharge, the others pay attention to effects of sea-level rise and land-use change. Various hydrological and groundwater flow models have been applied for the projections such as SWAT, MODFLOW, SEAWAT, and FEFLOW (Table. 1). Although those studies were performed in different areas and models, most of them share the similar ideas that groundwater recharge and fresh-groundwater availability will decrease due to climate change in coastal areas. These issues need to be taken into account in groundwater management in Vietnam.

In coastal areas, groundwater is vital resources for water supply but it is vulnerable to the seawater intrusion derived from sea level rise due to climate change. Hence, research on this issue and adaptation measures needs to be more concerned in the future.

In addition, there are still concerns for future studies on the impacts of climate changes:

- The groundwater recharge projected in previous studies mostly is the totality of recharge sources. Therefore, discriminating sources of recharge will clarify the contribution of rainfall, groundwater-surface water interaction and the others to groundwater system and, thus, give more insight into the impact of climate change. In areas, where agricultural activities are intensive, the return flow from irrigation water should be estimated in the projection model. This is because the response of groundwater to this recharge source is faster than changes in the recharge from rainfall and the quality of groundwater will also be affected.
- In the studies considering the effects of sea-level rise, the density difference between seawater and fresh groundwater did not specify, thus, the projected results may be overestimated because seawater with higher density would hardly move in the aquifer system than freshwater.
- There is a notable point that the impact of climate change on groundwater quality has not been investigated previously. Because recharge water mixing with original groundwater in the aquifer, it will change the groundwater quality due to the dilution or the disturbance derived from high dissolved oxygen water[54], increase dissolved organic carbon (DOC) in groundwater[55], and so on. Hence, the impact on groundwater quality is an important problem for future research.

- In every climate change scenario simulated for the impacts on groundwater, the adaption method is neglected. If the adaption methods are integrated into model simulations, it will give more information on their effectiveness for climate change adaptation strategies in Vietnam. There are considerably potential adaption methods such as Managed Aquifer Recharge [56] and maximizing efficient use of rainwater together with minimizing groundwater abstraction [57].

CONCLUSION

In the recent climate change condition, the role of groundwater becomes more important, especially when extreme weather like drought occurs. However, groundwater is also vulnerable to climate change. This paper gave a short review on the impacts of climate change on groundwater resources in Vietnam. The studies in Vietnam indicated that climate change directly affects groundwater through recharge from precipitation, and indirectly through changes in land use. The impacts are varied in extent in different areas but show negative effects on groundwater recharge and fresh groundwater availability. The potential topics for future research are also addressed in the paper. The knowledge provided from this paper can be considered for adaptation strategies for climate change and groundwater sustainable development.

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COMPETING INTERESTS

The authors declare no conflict of interest.

AUTHORS' CONTRIBUTIONS

Write the manuscript: P.N.L.; Collecting and analyzing the materials for the manuscript: P.T.L.

REFERENCES

1. Eckstein D, Künzel V, Schäfer L. Global Climate Risk Index 2021. Bonn, Germanwatch. 2021;.
2. Vo ND, Gourbesville P, Vu MT, Raghavan SV, Liong SY. A deterministic hydrological approach to estimate climate change impact on river flow: Vu Gia-Thu Bon catchment, Vietnam. Journal of Hydro-environment Research. 2016;11:59-74;Available from: https://doi.org/10.1016/j.jher.2015.11.001.
3. Thai TH, Thao NP, Dieu BT. Assessment and simulation of impacts of climate change on erosion and water flow by using the soil and water assessment tool and GIS: Case Study in Upper Cau River basin in Vietnam. Earth Sci. 2017;39(4):376-92;Available from: https://doi.org/10.15625/0866-7187/39/4/10741.
4. Hang NT, Phung NK. The Effect of Climate Change on the Surface Water Resources of the Lam Dong Province. Vietnam Journal of Hydrometeorology.;2019(02):25-34;.
5. Hoang LP, Lauri H, Kummu M, Koponen J, Van Vliet MT, Supit I, Leemans R, Kabat P, Ludwig F. Mekong River flow and hydrological extremes under climate change. Hydrology and Earth System Sciences. 2016;20(7):3027-41;Available from: https://doi.org/10.5194/hess-20-3027-2016.
6. Tri DQ, Tuyet QT. Effect of Climate Change on the Salinity Intrusion: Case Study Ca River Basin, Vietnam. Journal of Climate Change. 2016;2(1):91-101;Available from: https://doi.org/10.3233/JCC-160010.
7. Vu DT, Yamada T, Ishidaira H. Assessing the impact of sea level rise due to climate change on seawater intrusion in Mekong Delta, Vietnam. Water Science and Technology. 2018;77(6):1632-9;PMID: 29595165. Available from: https://doi.org/10.2166/wst.2018.038.
8. Khoi DN, Nguyen VT, Sam TT, Nhi PT. Evaluation on effects of climate and land-use changes on streamflow and water quality in the La Buong River Basin, Southern Vietnam. Sustainability. 2019;11(24):7221;Available from: https://doi.org/10.3390/su11247221.
9. Thi NG, Thi BT, Nguyen HT, Thanh VQ. Impact of climate change and socio-economic development on the water balance and water quality of the Can Tho River. InIOP Conference Series: Earth and Environmental Science 2021 Feb 1 (Vol. 652, No. 1, p. 012008). IOP Publishing;Available from: https://doi.org/10.1088/1755-1315/652/1/012008.
10. Dong ND, Jayakumar KV, Agilan V. Impact of climate change on flood frequency of the Trian Reservoir in Vietnam using RCMs. Journal of Hydrologic Engineering. 2018 Feb 1;23(2):05017032;Available from: https://doi.org/10.1061/(ASCE)HE.1943-5584.0001609.
11. Wagner F, Tran VB, Renaud FG. Groundwater resources in the Mekong Delta: availability, utilization and risks. InThe Mekong Delta System 2012 (pp. 201-220). Springer, Dordrecht;PMID: 22335418. Available from: https://doi.org/10.1007/978-94-007-3962-8_7.
12. Pham VH, Lee SI. Assessment of seawater intrusion potential from sea-level rise and groundwater extraction in a coastal aquifer. Desalination and Water Treatment. 2015;53(9):2324-38;Available from: https://doi.org/10.1080/19443994.2014.971617.
13. Ngo MT, Lee JM, Lee HA, Woo NC. The sustainability risk of Ho Chi Minh City, Vietnam, due to saltwater intrusion. Geosciences Journal. 2015 Sep;19(3):547-60;Available from: https://doi.org/10.1007/s12303-014-0052-4.
14. Erban LE, Gorelick SM, Zebker HA. Groundwater extraction, land subsidence, and sea-level rise in the Mekong Delta, Vietnam. Environmental Research Letters. 2014 Aug 15;9(8):084010;Available from: https://doi.org/10.1088/1748-9326/9/8/084010.
15. Minderhoud PS, Erkens G, Pham VH, Bui VT, Erban L, Kooi H, Stouthamer E. Impacts of 25 years of groundwater extraction on subsidence in the Mekong delta, Vietnam. Environmental research letters. 2017 Jun 1;12(6):064006;PMID: 30344619. Available from: https://doi.org/10.1088/1748-9326/aa7146.
16. Postma D, Larsen F, Thai NT, Trang PT, Jakobsen R, Nhan PQ, Long TV, Viet PH, Murray AS. Groundwater arsenic concentrations in Vietnam controlled by sediment age. Nature Geoscience. 2012 Sep;5(9):656-61;Available from: https://doi.org/10.1038/ngeo1540.
17. Erban LE, Gorelick SM, Fendorf S. Arsenic in the multi-aquifer system of the Mekong Delta, Vietnam: analysis of large-scale spatial trends and controlling factors. Environmental science & technology. 2014 Jun 3;48(11):6081-8;PMID: 24849074. Available from: https://doi.org/10.1021/es403932t.
18. Ha QK, Kim K, Phan NL, Phung TH, Lee J, Nguyen VK, Phan CN. A hydrogeological and geochemical review of groundwater issues in southern Vietnam. Geosciences Journal. 2019 Dec;23(6):1005-23;Available from: https://doi.org/10.1007/s12303-019-0021-z.
19. Jayakumar R, Lee E. Climate change and groundwater conditions in the Mekong Region-A review. Journal of Groundwater Science and Engineering Vol. 2016 Jun;4(2);.

20. Amanambu AC, Obarein OA, Mossa J, Li L, Ayeni SS, Balogun O, Oyebamiji A, Ochege FU. Groundwater system and climate change: Present status and future considerations. Journal of Hydrology. 2020 Oct 1;589:125163;Available from: https://doi.org/10.1016/j.jhydrol.2020.125163.
21. Canh DV. Hydrogeological condition in Vietnam - Groundwater in Vietnam. Vietnam National University. 2017;Available from: https://repository.vnu.edu.vn/flowpaper/simple_document.php?subfolder=32/60/59/&doc=3260597571450724700199023331093194755&bitsid=dbc383e0-85b5-424e-813d-73ba5e41afc0&uid=.
22. World Meteorological Organization, 2021. State of the Global Climate 2020. WMO-No. 1264. Geneva, Switzerland;.
23. Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, Church JA, Clarke L, Dahe Q, Dasgupta P, Dubash NK. Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. . Pachauri and L. Meyer (editors) , Geneva, Switzerland, IPCC. 2014; 151 p;.
24. Nguyen DQ, Renwick J, McGregor J. Variations of surface temperature and rainfall in Vietnam from 1971 to 2010. International Journal of Climatology. 2014 Jan;34(1):249-64;Available from: https://doi.org/10.1002/joc.3684.
25. Nakicenovic N, et al. IPCC Special Report on Emission Scenarios. Cambridge Univ. Press, Cambridge. 2000;.
26. Thuc T, Van Thang N, Huong HT, Van Khiem M, Hien NX, Phong DH. Climate change and sea level rise scenarios for Vietnam. Ministry of Natural resources and Environment. Hanoi, Vietnam. 2016;.
27. Shrestha S, Bach TV, Pandey VP. Climate change impacts on groundwater resources in Mekong Delta under representative concentration pathways (RCPs) scenarios. Environmental science & policy. 2016 Jul 1;61:1-3;Available from: https://doi.org/10.1016/j.envsci.2016.03.010.
28. Ha QK, K Sucharit. Impact of Climate Change on groundwater recharge in Ho Chi Minh City Area, Vietnam. InInt. Conf. on Climate Change and Water & Environment Management in Monsoon Asia, Bangkok, Thailand 2015;.
29. Shrestha S, Hoang NA, Shrestha PK, Bhatta B. Climate change impact on groundwater recharge and suggested adaptation strategies for selected Asian cities. APN Science Bulletin. 2018 Nov 29;Available from: https://doi.org/10.30852/sb.2018.499.
30. Lam QD, Meon G, Pätsch M. Coupled modelling approach to assess effects of climate change on a coastal groundwater system. Groundwater for Sustainable Development. 2021 Jun 25:100633;Available from: https://doi.org/10.1016/j.gsd.2021.100633.
31. Tam VT, Batelaan O, Beyen I. Impact assessment of climate change on a coastal groundwater system, Central Vietnam. Environmental Earth Sciences. 2016 May 1;75(10):908;Available from: https://doi.org/10.1007/s12665-016-5718-y.
32. Pholkern K, Saraphirom P, Srisuk K. Potential impact of climate change on groundwater resources in the Central Huai Luang Basin, Northeast Thailand. Science of the Total Environment. 2018 Aug 15;633:1518-35;PMID: 29758903. Available from: https://doi.org/10.1016/j.scitotenv.2018.03.300.
33. Soro GE, Yao AB, Kouame YM, Bi TA. Climate change and its impacts on water resources in the Bandama basin, Côte D'ivoire. Hydrology. 2017 Mar;4(1):18;Available from: https://doi.org/10.3390/hydrology4010018.
34. Schmidt-Thome P, Nguyen TH, Pham TL, Jarva J, Nuottimäki K. Climate change in Vietnam. In Climate change adaptation measures in Vietnam 2015 (pp. 7-15). Springer, Cham;Available from: https://doi.org/10.1007/978-3-319-12346-2_2.
35. Dung BQ, Khanh UD. CALCULATION OF VIETNAM'S COASTLINE LENGTH (MAINLAND) BASED ON TOPOGRAPHIC MAP SYSTEM AT SCALE 1/50,000. Vietnam Journal of Marine Science and Technology. 2016 Aug 31;16(3):221-7;Available from: https://doi.org/10.15625/1859-3097/16/3/8654.
36. Dang NM, Tung NB, Duong TA, Dang TD. Assessments of Climate Change and Sea Level Rise Impacts on Flows and Saltwater Intrusion in the Vu Gia-Thu Bon River Basin, Vietnam. InInternational Conference on Asian and Pacific Coasts. 2019 Sep 25 (pp. 1367-1374). Springer, Singapore;Available from: https://doi.org/10.1007/978-981-15-0291-0_185.
37. Hien NT, Yen NH, Balistrocchi M, Cat VM, Roberto R. Salinity dynamics under sea level rise scenarios in the Red-Thai Binh River delta, Vietnam. In22nd IAHR-APD Congress 2020 2020;.
38. Tam VT, Nga TT. Assessment of urbanization impact on groundwater resources in Hanoi, Vietnam. Journal of environmental management. 2018 Dec 1;227:107-16;PMID: 30172929. Available from: https://doi.org/10.1016/j.jenvman.2018.08.087.
39. Jafari H, Sudegi A, Bagheri R. Contribution of rainfall and agricultural returns to groundwater recharge in arid areas. Journal of Hydrology. 2019 Aug 1;575:1230-8;Available from: https://doi.org/10.1016/j.jhydrol.2019.06.029.
40. der Wolf MV. Effects of Land Use Change on Groundwater Recharge. A case Study in the Day River Basin, Vietnam. Master's Thesis, Utrecht University, Utrecht, The Netherlands, 2015;.
41. Vinh CT, Khuyen NM, Hieu NH, Van Long D, Bach NT, Van TT. Assessment of Groundwater Recharge from Rainfall in the Plain of Cai Phan Rang, Vietnam. Journal of Environmental Science and Engineering. A. 2014 Mar 1;3(3A);.
42. Milnes E, Negro F, Perrochet P. Vietnam to Produce More Coffee with Less Water-Towards a Reduction of the Blue Water Footprint in Coffee Production. Hydrogeological Study of the Basaltic Plateau in Dak Lak Province, Vietnam; Université de Neuchâtel: Neuchâtel, Switzerland. 2015;.
43. Vu VH, Merkel BJ. Estimating groundwater recharge for Hanoi, Vietnam. Science of The Total Environment. 2019 Feb 15;651:1047-57;PMID: 30266050. Available from: https://doi.org/10.1016/j.scitotenv.2018.09.225.
44. Dang VH, Tran DD, Cham DD, Hang PT, Nguyen HT, Truong HV, Tran PH, Duong MB, Nguyen NT, Le KV, Pham TB. Assessment of Rainfall Distributions and Characteristics in Coastal Provinces of the Vietnamese Mekong Delta under Climate Change and ENSO Processes. Water. 2020 Jun;12(6):1555;Available from: https://doi.org/10.3390/w12061555.
45. Vu HM, Shanafield M, Batelaan O. Flux dynamics at the groundwater-surface water interface in a tropical catchment. Limnologica. 2018 Jan 1;68:36-45;Available from: https://doi.org/10.1016/j.limno.2017.06.003.
46. Huyen NT, Tu LH, Tram VN, Minh DN, Liem ND, Loi NK. Assessing the impacts of climate change on water resources in the Srepok watershed, Central Highland of Vietnam. Journal of Water and Climate Change. 2017 Sep;8(3):524-34;Available from: https://doi.org/10.2166/wcc.2017.135.
47. Adhikari RK, Mohanasundaram S, Shrestha S. Impacts of land-use changes on the groundwater recharge in the Ho Chi Minh city, Vietnam. Environmental research. 2020 Jun 1;185:109440;PMID: 32247909. Available from: https://doi.org/10.1016/j.envres.2020.109440.
48. Pham VH, Van Geer FC, Tran VB, Dubelaar W, Essink GH. Paleo-hydrogeological reconstruction of the fresh-saline groundwater distribution in the Vietnamese Mekong Delta since the late Pleistocene. Journal of Hydrology: Regional Studies. 2019 Jun 1;23:100594;Available from: https://doi.org/10.1016/j.ejrh.2019.100594.
49. Schmidt-Thome P, Nguyen TH, Pham TL, Jarva J, Nuottimäki K. Impacts of Climate Change on the Thanh Hoa Province. InClimate Change Adaptation Measures in Vietnam 2015 (pp. 17-44). Springer, Cham;Available from: https://doi.org/10.1007/978-3-319-12346-2_3.
50. Schmidt-Thome P, Nguyen TH, Pham TL, Jarva J, Nuottimäki K. Impacts of Climate Change on the Ba Ria-Vung Tau Province. In Climate Change Adaptation Measures in Vietnam 2015 (pp. 45-68). Springer, Cham;Available from: https://doi.org/10.1007/978-3-319-12346-2_4.

51. Jasechko S, Perrone D, Seybold H, Fan Y, Kirchner JW. Groundwater level observations in 250,000 coastal US wells reveal scope of potential seawater intrusion. Nature communications. 2020 Jun 26;11(1):1-9;PMID: 32591535. Available from: https://doi.org/10.1038/s41467-020-17038-2.
52. Romanazzi A, Gentile F, Polemio M. Modelling and management of a Mediterranean karstic coastal aquifer under the effects of seawater intrusion and climate change. Environmental Earth Sciences. 2015 Jul;74(1):115-28;Available from: https://doi.org/10.1007/s12665-015-4423-6.
53. Ketabchi H, Mahmoodzadeh D, Ataie-Ashtiani B, Simmons CT. Sea-level rise impacts on seawater intrusion in coastal aquifers: Review and integration. Journal of Hydrology. 2016 Apr 1;535:235-55;Available from: https://doi.org/10.1016/j.jhydrol.2016.01.083.
54. Ha QK, Choi S, Phan NL, Kim K, Phan CN, Nguyen VK, Ko KS. Occurrence of metal-rich acidic groundwaters around the Mekong Delta (Vietnam): A phenomenon linked to well installation. Science of the Total Environment. 2019 Mar 1;654:1100-9;PMID: 30841385. Available from: https://doi.org/10.1016/j.scitotenv.2018.11.200.
55. McDonough LK, Santos IR, Andersen MS, O'Carroll DM, Rutlidge H, Meredith K, Oudone P, Bridgeman J, Gooddy DC, Sorensen JP, Lapworth DJ. Changes in global groundwater organic carbon driven by climate change and urbanization. Nature communications. 2020 Mar 9;11(1):1-0;PMID: 32152271. Available from: https://doi.org/10.1038/s41467-020-14946-1.
56. Ha NT, Jarva J, Nuottimäki K, Long PT, Trung DT, Van Duy H, Hong NT, Hung NK. Managed aquifer recharge to ensure sustainable groundwater availability and quality under ongoing climate change and rapid economic development in Vietnam (Viet MAR). 55th CCOP Annual Session, 5-6 November 2019, Chiang Mai, Thailand;.
57. Dang VH, Tran DD, Cham DD, Hang PT, Nguyen HT, Truong HV, Tran PH, Duong MB, Nguyen NT, Le KV, Pham TB. Assessment of Rainfall Distributions and Characteristics in Coastal Provinces of the Vietnamese Mekong Delta under Climate Change and ENSO Processes. Water. 2020 Jun;12(6):1555;Available from: https://doi.org/10.3390/w12061555.

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Tổng quan

Tác động của biến đổi khí hậu đến tài nguyên nước dưới đất: bài tổng quan ngắn

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TÓM TẮT

Nước dưới đất là nguồn tài nguyên quan trọng trong việc thích ứng với biến đổi khí hậu ở Việt Nam. Tuy nhiên, tài nguyên nước dưới đất cũng bị ảnh hưởng bởi biến đổi khí hậu và các ảnh hưởng này chỉ mới nhận được nhiều sự quan tâm hơn trong những năm gần đây. Mặc dù vậy, nhiều nghiên cứu đã được thực hiện để đánh giá tác động của biến đổi khí hậu đến tài nguyên nước dưới đất. Các nghiên cứu này được thực hiện ở miền Bắc (Hà Nội và Nam Định), miền Trung (Bình Định, lưu vực sông Serapok, và Thanh Hóa) và miền Nam Việt Nam (Thành phố Hồ Chí Minh, Bà Rịa – Vũng Tàu, và đồng bằng sông Cửu Long). Các mô hình thủy văn và nước dưới đất là công cụ đắc lực được sử dụng trong các nghiên cứu này. Ngoài ra, sự thay đổi lượng mưa, mực nước biển dâng và đô thị hóa là những yếu tố được dự báo trong các kịch bản biến đổi khí hậu để đánh giá tác động; lượng bổ cập nước dưới đất, mực nước và chất lượng nước dưới đất là các thành phần của nước dưới đất được đánh giá tác động của biến đổi khí hậu. Dựa trên sự đánh giá của các yếu tố khí hậu lên thành phần của nước dưới đất, rất nhiều kết luận ý nghĩa đã được đưa ra. Bài báo này tóm tắt kết quả của các nghiên cứu gần đây về tác động của biến đổi khí hậu đến tài nguyên nước dưới đất ứng với các kịch bản biến đổi khí hậu ở Việt Nam. Phần lớn các nghiên cứu cho tới hiện nay đều cho thấy các tác động tiêu cực là biến đổi khí hậu sẽ làm giảm lượng bổ cập nước dưới đất và giảm lượng nước nhạt hoặc làm tăng sự mặn hóa nước dưới đất, chủ yếu ở các khu vực ven biển. Nguyên nhân chính của tác động này là do sự thay đổi lượng mưa, sự thay đổi sử dụng đất do ảnh hưởng của biến đổi khí hậu và mực nước biển dâng. Những nghiên cứu trên đã truyền tải những thông tin giá trị cho việc quản lý tài nguyên nước dưới đất và chiến lược ứng phó biến đổi khí hậu ở Việt Nam. Bên cạnh sự đa dạng của các nghiên cứu, vẫn còn những vấn đề liên quan đến tác động qua lại giữa biến đổi khí hậu và nước dưới đất như ảnh hưởng gián tiếp của biến đổi khí hậu từ việc tăng lượng khai thác nước dưới đất và/hoặc canh tác nông nghiệp quá mức trong tương lai. Những vấn đề này sẽ là chủ đề tiềm năng cho nghiên cứu trong tương lai.

Từ khoá: Biến đổi khí hậu, nước dưới đất, lượng bổ cập nước dưới đất, mực nước biển dâng

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