Study on Establishing a Monitoring System for Groundwater in the Condition of Climate Change and Sea Level Rise: Case Study of Ma River Basin in Vietnam

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Abstract: The results presented in this paper are a part of the research results of the thesis “research on scientific basis and practice of develop a system of monitoring the impacts of climate change on surface water and groundwater”. Case study: Ma river basin in Vietnam. The results were implemented: (i) data collection, fieldwork survey, synthesis and analysis of information and data; (ii) partitioning the influence degree of climate change and sea level rise to groundwater; (iii) determining criteria to select monitoring routes, location of monitoring groundwater in the condition of climate change and sea level rise and (iv) developing the monitoring system. The research’s results have practical implications for the water resources management in the context of climate change and sea level rise in Ma river basin.

Key words: Groundwater monitoring system, climate change, sea level rise.

1. Introduction

Ma river originates from the mountains Pu Huoi Long belongs to Tuan Giao district, Dien Bien province in Vietnam, at an altitude of 2,178 m and then flows from the northwest-southeast through Son La province, then flows to Luong Pha Bang-Laos, continues flow back to Thanh Hoa province, Vietnam and empties to the sea at 3 large river mouths Cua Hoi, Lach Sung and Lach Truong. The length of main line of Ma river is about 512 km, the catchment area of about 28,400 km² (37.6% of Laos, 62.4% of Vietnam’s) (Fig. 1). The total annual flow is 18 billion m³. However, floods usually occur in rainy season, the lack of water often occurs in dry season, groundwater resources reserves are declining, salinization of coastal areas happens due to the impact of climate change and sea-level rise. Therefore, this study will analyze the data and partition impact of climate change on groundwater, propose the groundwater

monitoring system in Ma river basin in order to warn and forecast ground water resources in the context of climate change, sea level rise as a basis for water resource management agencies proposing the effective management and use solutions of water resources in river basin.

2. Approach and Research Methods

2.1 Approach Methods

To get the results of research, the authors have taken the following approach methods:

- (1) Data collection, field survey, aggregate, analyze information and data;
- (2) Assess, partition the affected level of climate change and sea level rise to groundwater that considering the planning of groundwater use and extraction [1];
- (3) Determine criteria to select monitoring routes, location of groundwater monitoring in terms of climate change and sea level rise;
- (4) Develop monitoring systems.

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Fig. 1 Geographic location of Ma river basin belongs to the northwest and the north central areas of Vietnam.

2.2 Research Methods

(1) Inheritance method: use the documents of topography, geology, water resources monitoring data, hydrometeorology data, climate change scenarios and inherit the previous research results on water resources;

(2) Field survey: measure the water level, discharge, current state of water resources exploitation, survey and interview to collect data on the groundwater exploiting works [2];

(3) Methods of simulation on GIS: study the geological structure, topography surface [3] and mapping observations; building water level contour, determine the destructive dynamic area based on the results of monitoring groundwater in wells belonging to national monitoring network;

(4) Statistical analysis method: assess the correlation between sea level rise and groundwater;

(5) Expert method: get the feedback comments for good results and report.

3. Results and Discussion

3.1 Partitioning the Affected Level of Climate Change, Sea Level Rise to Groundwater

3.1.1 Status of the Groundwater Dynamic Areas

Based on the current status of the saline aquifer and the results of groundwater monitoring in the wells belonging to the national monitoring network (Table 1), the authors mapped the dynamic areas of groundwater, saline areas and presented in Fig. 2 [4, 5].

Fig. 2 shows the Thanh Hoa plain area has the natural movement zone a, destructive movement zone b, c and salinity zone d. Destructive movement zone b, c formed the water lower funnel due to the impact of centralized groundwater exploiting facilities supplying water for domestic and production purposes.

3.1.2 Assess the Change of Groundwater Dynamic Areas under the Impact of Climate Change, Sea Level Rise and Planning Groundwater Extraction

The medium scenario B2 “scenarios of climate change and sea level rise for Vietnam” [6] which was

Table 1 Water level in monitored wells at the present time.

No.	Symbol	X	Y	Altitude of monitored wells	The water levels ZHt (m)
1	QT1	565,038	2,212,407	10.7	3.6
2	QT2	584,253	2,202,284	6.0	2.5
3	QT4	552,316	2,206,326	13.7	6.1
4	QT5	559,540	2,203,934	10.2	4.5
5	QT6	567,687	2,197,597	7.3	3.3
6	QT7	576,514	2,193,611	5.6	1.6
7	QT8	584,852	2,189,198	3.5	0.7
8	QT9	592,961	2,182,752	3.6	2.3
9	QT10	556,745	2,196,148	6.9	5.4
10	QT11	571,401	2,179,939	3.8	2.3
11	QT12	582,797	2,169,703	3.6	1.9
12	QT13	602,146	2,210,853	4.0	0.5
13	QT14	580,449	2,162,280	5.9	3.6

Fig. 2 Diagram of the the state of the groundwater movement areas and salinity areas in Ma river basin.

published by Vietnamese Ministry of Natural Resources and Environment in 2012 showed the annual rainfall (%) and sea level rise in comparison

with the period of 1980-1999 in the study area (Thanh Hoa-North Central region) and these are shown in Tables 2-4.

Table 2 The level change (%) of seasonal rainfall compared to the period of 1980-1999 according to the medium emissions scenario (B2).

No	Season	The change of precipitation (%) according to the timeline								
		2020	2030	2040	2050	2060	2070	2080	2090	2100
1	Winter (XII-II)	0.7	1.0	1.4	1.8	2.2	2.6	2.9	3.2	3.5
2	Spring (III-V)	-1.0	-1.4	-2.0	-2.6	-3.1	-3.6	-4.1	-4.5	-4.9
3	Summer (VI-VIII)	2.3	3.4	4.8	6.2	7.5	8.7	9.8	10.9	11.8
4	Autumn (IX-XI)	0.9	1.3	1.9	2.4	3.0	3.5	3.9	4.3	4.7

Table 3 Forecast of monthly, yearly rainfall (mm) in the case study from 2020 to 2100 corresponds with climate change scenarios and sea level rise.

No	Timeline	Monthly rainfall (mm)												Yearly rainfall (mm)
		I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
1	2020	20.7	23.8	41.3	60.5	141.9	188.7	198.6	281.9	383.7	268.9	78.2	26.4	1,714.6
2	2030	20.8	23.8	41.1	60.2	141.3	190.8	200.7	285.0	385.2	270.0	78.5	26.5	1,723.9
3	2040	20.9	23.9	40.9	59.9	140.4	193.4	203.4	288.8	387.5	271.6	79.0	26.6	1,736.2
4	2050	21.0	24.0	40.6	59.5	139.6	195.9	206.1	292.7	389.4	272.9	79.4	26.7	1,747.8
5	2060	21.1	24.1	40.4	59.2	138.9	198.3	208.7	296.3	391.7	274.5	79.8	26.8	1,759.7
6	2070	21.1	24.2	40.2	58.9	138.1	200.6	211.0	299.6	393.6	275.8	80.2	26.9	1,770.2
7	2080	21.2	24.3	40.0	58.6	137.4	202.6	213.1	302.6	395.1	276.9	80.5	27.0	1,779.3
8	2090	21.3	24.4	39.8	58.4	136.9	204.6	215.3	305.6	396.7	278.0	80.8	27.0	1,788.6
9	2100	21.3	24.4	39.7	58.1	136.3	206.3	217.0	308.1	398.2	279.0	81.1	27.1	1,796.6

Table 4 Sea level rise (cm) in the case study from 2020 to 2100 corresponds with climate change scenarios (B2).

Timeline	2020	2030	2040	2050	2060	2070	2080	2090	2100
Sea level rise	8	12	16	22	28	35	42	49	57

3.1.2.1 Forecast the Change of the Groundwater Movement Areas under the Impact of Climate Change, Sea Level Rise and the Plan on Groundwater Exploitation

The results of monitoring groundwater in wells and rainfall in the study area showed the depth of groundwater levels closely correlated with precipitation which are shown in Fig. 3.

Fig. 3 shows that rainfall is closely related with groundwater dynamics. The relationship of precipitation is inversely with groundwater level and is represented by the correlation Eq. (1):

Natural dynamic area:

$$Hdd = -0.001 W + 3.758 \quad (1)$$

Where, Hdd: groundwater depth (m), W: precipitation (mm).

From Fig. 3, it can predict water level changes in the monitoring wells in the natural dynamics areas as

in Table 5.

According to the planning of exploitation and use of groundwater in the study area, there are 12 works by 2030, the location of the works are shown in Fig. 4, and based on the hydrogeological characteristics of the study area, the authors predict lowering water level in some areas shown in Table 6.

3.1.2.2 Partition Groundwater Movement Areas

From the results of Tables 4-6, the authors partition the dynamic areas in Fig. 5. Thus, in the condition of climate change, sea level rise and climate change the natural dynamics area (area a), destroyed dynamic area (area b, c and d) and the salinized areas by the sea level rise (area e) can be identified.

On this basis, the authors identify the monitoring network in the condition of climate change, sea level rise and planning of exploitation.

3.2 Criteria for Determining

3.2.1 Type of Monitoring Stations

According to EU Directive, there have been 3 types of monitoring stations [7] as follows:

- Trend surveillance station (surveillance) monitoring the natural dynamics;
- Operational monitoring station (operational) monitoring destroy dynamics areas;
- Enforcement monitoring station (enforcement) monitoring the extraction of wells and its locations next to exploitation wells. In this study, the authors did not build this station type, because according to the provisions of the Water Resources Act, the work's owners must build them.

On this basis, the authors identify the monitoring

routes and works like Fig. 6 as follows:

- Trend surveillance stations, including single wells are QT2, QT10 and QT11, routes of monitoring salinity trend are I, II, III, IV and V and trends relations between rivers and groundwater is X;
- Operational monitoring stations, including the VII, VIII and IX.

3.2.2 Wells Detailed Arrangements on the Monitoring Routes

Route 1:

- Purpose: monitoring saltwater intrusion trends (Fig. 7).
- Route includes 01 well field (QT13) with 02 works arranged perpendicularly to the salty border in order to monitor salinity intrusion and natural dynamic in Nga Hung Commune, Nga Son district.

Fig. 3 Graph of correlation between the water level of well QT8 and precipitation in the natural dynamic region.

Table 5 Water levels of wells in the natural dynamics areas in 2100 under the impact of climate change.

No	Symbol	X	Y	Altitude of monitoring wells	The water levels ZHt (m)
1	QT1	565,038	2,212,407	10.7	3.8
2	QT2	584,253	2,202,284	6.0	2.7
3	QT4	552,316	2,206,326	13.7	6.3
4	QT6	567,687	2,197,597	7.3	3.5
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6	QT9	592,961	2,182,752	3.6	2.5
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9	QT12	582,797	2,169,703	3.6	2.1
10	QT13	602,146	2,210,853	4.0	0.7
11	QT14	580,449	2,162,280	5.9	3.8

Fig. 4 Location and discharge of groundwater extraction wells in planning projects.

Table 6 Water levels in the wells in destroyed dynamic areas by 2030.

TT	District/town/city	Using demand (m ³ /day)	Current water level Ht (m)	Lower water level in predicted destruction dynamic area SHt (m)	Water level of predicted destruction dynamic area Hd (m)
1	Dong Son	5,000	4.1	3.2	7.3
2	Ha Trung	7,000	2.5	4.5	7.0
3	Hau Loc	11,000	1.0	4.4	5.4
4	Hoang Hoa	8,000	4.1	5.1	9.2
5	Nga Son	6,000	2.4	3.8	6.2
6	Nong Cong	5,000	1.4	3.2	4.6
7	Quang Xuong	3,000	1.8	1.9	3.7
8	Thieu Hoa	4,000	5.4	2.6	8.0
9	Tho Xuan	16,000	8.6	10.2	18.8
10	Trieu Son	7,000	1.5	4.5	6.0
11	Vinh Loc	2,000	6.0	1.3	7.3
12	Yen Dinh	9,000	14.4	5.8	20.2

Fig. 5 Partition the destructive movement areas, effected by salinity intrusion in the context of Climate Change (CC), sea level rise and the plan on Groundwater Exploitation (GE).

Route 2:

- Purpose: monitoring salinity intrusion trends (Fig. 8).
- Route includes 02 well fields (QT3, QT22) with 04 works arranged perpendicularly to the salty border in order to monitor saline intrusion and natural dynamic in Hoang Yen Commune, Hoang Hoa district.

Route 3:

- Purpose: monitoring salinity intrusion trends (Fig. 9).
- Route includes 02 well clusters (QT23, QT9) with 04 works arranged perpendicularly to the salty border, monitor salinity intrusion and natural dynamic in Truong Son ward, Sam Son town.

Fig. 6 Layout of observation network in the condition of climate change, sea level rise and the plan on exploitation.

Fig. 7 Section diagram of monitoring route 1.

Fig. 8 Section diagram of monitoring route 2.

Fig. 9 Section diagram of monitoring route 3.

Route 4:

- Purpose: monitoring salinity intrusion trends (Fig. 10).
- Route includes 02 well clusters (QT24, QT12) with 04 works arranged perpendicularly to the salty border, monitor salinity intrusion and natural dynamic in Quang Trung Commune, Quang Xuong district.

Route 5:

- Purpose: monitoring salinity intrusion trends (Fig. 11).
- Route includes 01 well cluster (QT14) with 02 works arranged perpendicularly to the salty border, monitor salinity intrusion and natural dynamic in Ngoc Linh Commune, Tinh Gia district.

Fig. 10 Section diagram of monitoring route 4.

Fig. 11 Section diagram of monitoring route 5.

Route 6:

- Purpose: monitoring saltwater intrusion trends (Fig. 12).

- Route includes 02 well clusters (QT15, QT16) with 04 works arranged perpendicularly to the salty border, monitor salinity intrusion and natural dynamic in Hoang Hoa Commune, Hoang Hoa district.

Route 7:

- Purpose: monitoring operation of funnel-shaped lower water level area (Fig. 13).

- Route includes 04 well clusters (QT14) with 08 works arranged perpendicularly to the direction of lower water level line, namely: cluster QT1-monitoring lower water level funnel caused by water plant in Dinh Tuong Commune, Yen Dinh district; cluster QT18, QT7 and QT17-monitoring lower water level funnel caused by water plant at Van Ha Commune, Thieu Hoa district.

Route 8:

- Purpose: monitoring operation of funnel-shaped lower water level area (Fig. 14).

- Route includes 03 well clusters (QT4, QT21 and QT20) with 06 works arranged perpendicularly to the direction of lower water level line caused by Tho Xuan water plant, Tho Xuan district.

Route 9:

- Purpose: monitoring operation of funnel-shaped lower water level area (Fig. 15).

- Route includes 03 well clusters (QT6, QT18 and QT19) with 06 works arranged perpendicularly to the direction of lower water level line caused by water plant in Van Ha Commune, Thieu Hoa district.

Route 10:

- Purpose: monitoring trends on the relation between river water and groundwater (Fig. 16).

- Number of monitoring works: Route includes 01 well cluster (QT8) with 02 works arranged perpendicularly to the river [8].

4. Conclusion

(1) Assessing and forecasting changes of groundwater

level in the conditions of climate change, sea level rise and planning exploiting water in the study area;

(2) Developing the network of monitoring groundwater in the context of climate change, sea level rise, taking into consideration the plan on exploiting and using groundwater, and identify the specific monitoring target of each route and each well on route.

Fig. 12 Section diagram of monitoring route 6.

Fig. 13 Section diagram of monitoring route 7.

Fig. 14 Section diagram of monitoring route 8.

Fig. 15 Section diagram of monitoring route 9.

Fig. 16 Section diagram of monitoring route 10.

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