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APPLICATION OF ARTIFICIAL STORAGE, RECHARGE FOR SEMI-ARID AREA IN BACBINH VIETNAM

BacBinh is a sand dune area located in the southern part of central Vietnam. This area is confronted with a lack of water supply. The project aims to investigate the site for artificial recharge (AR) and the management of aquifer recharge (MAR) in the sand dune area. The geological setting of the area is characterised by ryo-dacitic bedrock, which forms steep isolated hills (up to 300 m a.s.l.) overlain by a Pleistocene-Holocene marine sand dunes plateau (up to 200 m a. s. l.). This is represented by prevailing white fine sand (Pleistocene) and prevailing red sand (Holocene), which occurs extensively in the coastal area. The hydrological and geological conditions are investigated by collecting all existing data of aerial and satellite photos, rainfall statistics, morphological/geological/ and hydrogeological maps for acquisition and interpretation. The field geophysical surveys are carried out for the location of groundwater aquifers to site selection, monitoring and operation of groundwater recharge. Hydrochemical and isotopic characterisation of surface water and groundwater in different periods showed that the sand dunes aquifers, with electrical conductivity ranging from 100 to 400 μS/cm, are composed of different water types, characterised by complex mixing processes. The site chosen for the artificial recharge, where 162 days of pumping tests have been carried out, proved that the use of the bank filtration technique has considerably improved the quality of water, which was originally highly contaminated by E-coli bacteria. The well field developed within the present project is now capable of supplying 220 m^3/day of good water quality to the HongPhong community, BacBinh district, which were recurrently affected by severe droughts.

Keywords: Basement investigation; management of aquifer recharge; water resources; groundwater monitoring

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1. Introduction

Water shortage has been identified as one of the major problems for the new Millennium, together with global warming. Management of water resources is by any means a new challenge, and the control and use of water have been a matter of importance from time immemorial. The provision of safe drinking water becomes a greater challenge as socio-economic development and population growth place increasing demands on limited water resources. In developing countries such as Vietnam, there is frequently uncertain access to reliable supplies of potable water. Both rural and urban populations lack reticulated systems and depend mainly on access to groundwater.

Management of Aquifer Recharge (MAR) describes intentional banking and treatment of water in aquifers. The term ‘Artificial recharge’ has also been used to describe this, but adverse connotations of ‘Artificial’ in a society where community participation in water resources management is becoming more prevalent, suggested that it was time for a new name. The old name incorrectly implied that the water was in some way unnatural. The recharge management is intentional as opposed to the effects of land clearing, irrigation, and installing water mains where recharge increases are incidental. MAR has also been called enhanced recharge, water banking and sustainable underground storage [3,4,6,7,27,28]. MAR often provides the cheapest form of new safe water supply for towns and small communities [10,16]. By means of training and demonstration projects, MAR has the potential to be a major contributor to the UN Millennium Goal for Water Supply, especially for village supplies in semi-arid and arid areas. The extent to which MAR can achieve its potential for water supplies will depend on an understanding of the capabilities and limitations of various techniques to use within the water catchment and aquifer system concerning the needs, existing water infrastructure, space for water harvesting, social and regulatory environment, and skills of personnel. The aquifer provides a store of groundwater, which, if utilised and managed effectively, can play a vital role in poverty reduction, risk reduction (both economic and health), increased yields resulting from reliable irrigation, increased economic returns and reduced vulnerability [2,18,21,23,30]. Sand dunes are widely distributed along with coastal areas in the Central part of Vietnam. In the last ten years, considerable water shortage or even severe droughts occurred more repeatable in the dry seasons [8,9,27,28].

The study area is located in the BacBinh district, BinhThuan province, where the extensive red coastal sand dunes occur. This area is the driest part of Vietnam, with the annual rainfall ranging less than 600 mm/yr between latitudes 11°01’00 and 11°05’00 N, and longitudes 108°15’00 and 108°22’ 00 E (Fig. 1). BauThieu mountain is situated in the study area, with a maximum of 302 m of elevation, and the rest is a hilly and coastal plain with changeable relief from west to east. There are no surface water sources. The groundwater has been a source of water supply, and an enhancement of recharge is a way of securing supplies and protecting against a decline in water quality for this area. It is understood that aquifers provide a store of groundwater, which, if utilised and managed effectively, can play a vital role in poverty reduction, risk reduction, increased yields resulting from reliable irrigation, increased economic returns and reduced vulnerability. For sustainable development of water resources, artificial recharge is one of many techniques being promoted as a solution to water supply in 21 century. The effectiveness of artificial recharge schemes is governed by climate, geology, hydrology, hydrogeology, topography, source water availability and quality, operational and management issues, regulatory controls and environmental and socio-economic consideration [5,15,24]. This paper is discussed to demonstrate the need to understand the surface water and groundwater system before implementing a project and results of studying on AR of groundwater in BacBinh area [25,27].

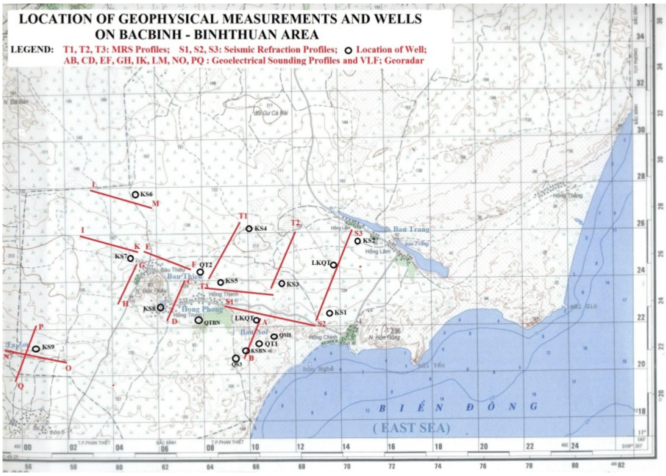

Fig. 1. Location of research project for MAR in BacBinh, BinhThuan, Vietnam and location of sub-regions: TaZon, BauThieu, BauTrang, BauNoi/geophysical measurements/ boreholes on study area

2. Overview of the study area

The general climatic conditions in the coastal area are characterised by low rainfall and a long, hot, dry season. There is suitable agricultural land that can only grow crops during the very short wet season. Extensive red-sand coastal dunes occur throughout the studying area.

Geological units of the coastal sand dune area located in BinhThuan are mainly Pleistocene sediments, consisting of marine-aeolian sediments of PhanThiet formation (mvQII-IIIpt), alluvial-marine (amQII-III), and marine (mQI, mQIII) sediments. The Pleistocene aquifers are unconfined, however, in some areas, groundwater is confined with a low-pressure head. Aquifer lithology is from fine- to medium-grained quartz sand, mixed with some silt and clay, of a typical red colour. Underlying Quaternary and Neogene sediments are hard rocks of igneous & metamorphic origins like dacite-ryodacite, which have very low permeability and cannot be considered as potential aquifers (see Fig. 2). Several morphological depressions (20-30 m a.s.l.)

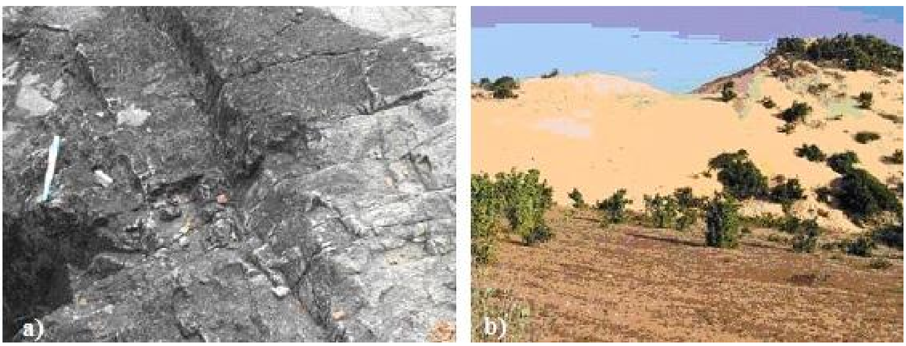

Fig. 2. Bedrock in HongPhong (a) and Red sand in the coastal area (b)

occur in marine sand dunes that form either wetlands or reservoirs such as the TaZon, BauNoi and BauTrang. The BauNoi pond was formed in October 2004 (approx. 3 km SE of HongPhong commune) due to the uprising of the piezometric head of the aquifer following heavy rains. BauNoi is very similar to BauTrang, some 9 km NE of HongPhong, which is a natural reservoir supplied by groundwater [8,9,14,28].

Groundwater is exploited through direct pumping where the aquifer emerges (TaZon, Bau Trang) or through shallow hand-dug wells. Surface water is only from rainwater collected on rooftops or by artificial reservoirs E and W of mount BauThieu but the quality of water there is not satisfactory [28].

A valuable approach to increase the volume of water supplies and maintain groundwater-dependent ecosystems is to have adequate management of aquifer recharge (MAR). MAR can also improve the security and quality of water supplies and protect water resources from saline intrusion. MAR was carried out in sand dunes coastal areas of Vietnam to fight desertification, for best practises on ecosystems rehabilitation and remediation techniques to restore aquifer systems and groundwater storage capacity [4,25,27].

3. Hydrological/Hydrogeological and Geophysical Investigations

The project in BacBinh area was carried out according to the recommendation of IAH through its Commission on MAR [4,25].

Hydrological and hydrogeological study

Due to an uneven rainfall distribution (600 mm/year on average) with a period of four months (from December to March) experienced very little precipitation (average 23 mm in 4 months), the area suffers considerable water shortage during the dry season. The rainy season has rapid runoff and high evaporation rates [8,9,27,28]. Some of the runoff is retained by surface storages (BauThieu and N and S of HongPhong village), but most of it infiltrates into the sand dunes. The marine sand dunes formation is characterised by the occurrence of an unconfined porous aquifer of variable thickness (40 to 60 m), emerging at ground level in depressed morphological areas (20 to 30 m a.s.l.) and forming wetlands or natural reservoirs. In particular, in the BauNoi area, November 1999 (approximately 3 km SE of HongPhong village), a pool was formed due to the rising of the piezometric head of the aquifer and consequently the direct infiltration into the sand aquifer during the last 25 years (since removing the land cover). This pool is perennial, and only slight level changes during the wet and the dry seasons are observed (Fig. 3a). The sand dune aquifer is exploited by direct pumping in places where it emerges (in depressed morphology) or through shallow hand-dug wells (5 to 8 m deep). During the dry season, the need for water for the population becomes urgent. In March 2004-2014, the majority of the shallow wells were dry (Fig. 3b).

The results of hydrogeological investigation campaigns during 2004-2016 agreed with the working hypotheses about stratigraphy and lithofacies (Fig. 4) and the conceptual scheme of hydrogeology (Fig. 5) proposed by P. Bono [26]. The scheme shown in Fig. 4 and 5 reveals that the coastal area contains plenty of springs with big yields and good quality. The water quality parameters measured in springs using a portable instrument showed a pH between 5,1 and 8,04,

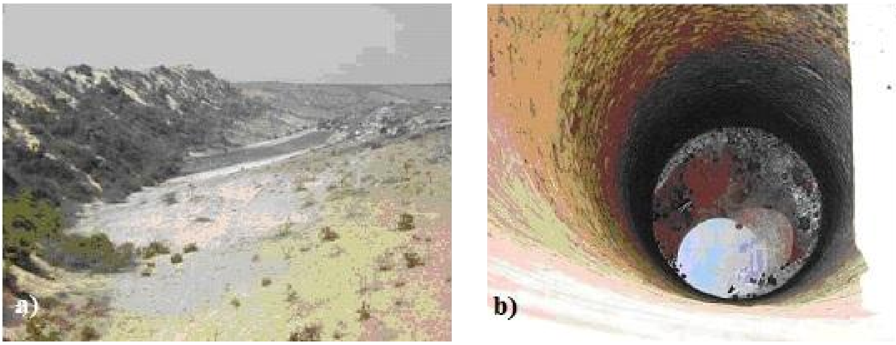

Fig. 3. Natural reservoir BauNoi (a) and Large diameter shallow well in HongPhong area (b)

temperature between 25.5-34.1°C, the electrical conductivity of 53-431 μS/cm, and corresponding total dissolved solids (TDS by EC) of 30-246 mg/l [27,28], that is the mineralisation of discharging groundwater is very low compared with some brackish coastal wells and seawater (Tab. 1).

The investigation included the following: acquisition & interpretation of existing data, acquisition of topographic, geological & hydrogeological maps, aerial & satellite photos, precipitation data, field geophysical & hydrogeological surveys, groundwater physio-chemical parameters measurements, groundwater sampling of water quality and isotopes analyses. Sixteen

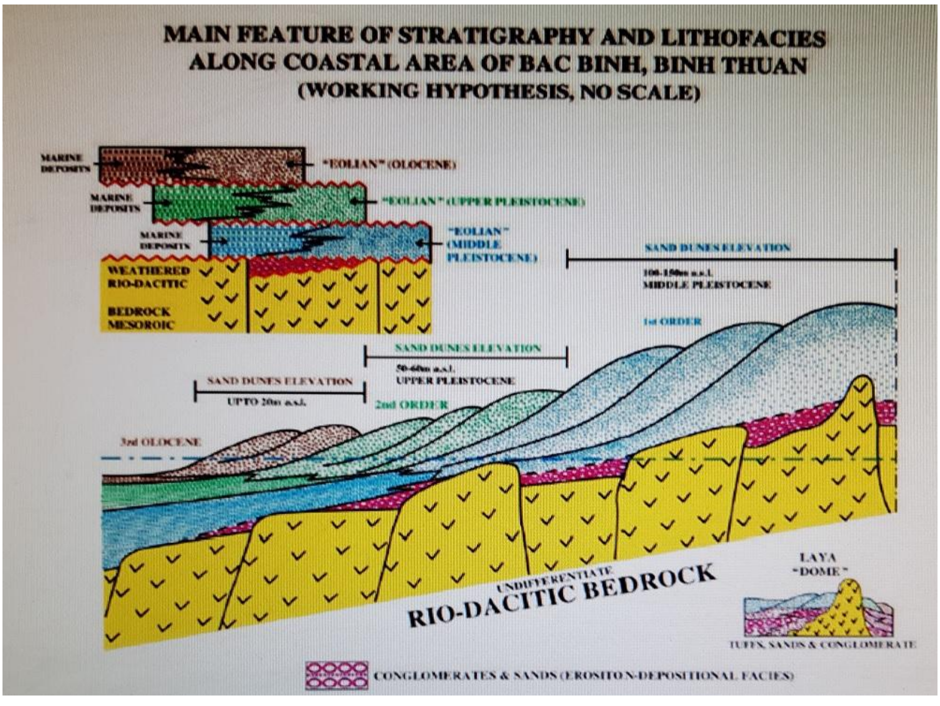

Fig. 4. Stratigraphy and lithofacies of BacBinh area (Hypothesis of P. Bono) [26]

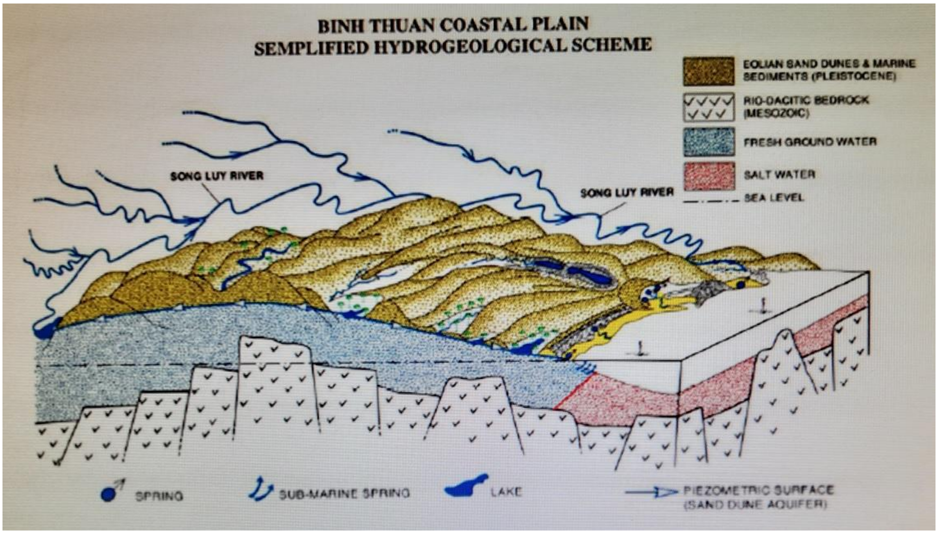

Fig. 5. Hydrogeological scheme proposed by P.Bono [26]

hydrogeological campaigns during 2004-2016 carried out in a selected network of wells, springs, lakes, and ponds gave the basic information on the major parameters of BacBinh water resources.

Water sources

One of the factors that play a crucial role in the success of a MAR project is the potential water source for recharge. The rainwater source was estimated based on analysis of meteorological data from two installed stations in BauNoi and HongPhong village. This data was from 2005. According to 2 years average rainfall data of BauNoi and HongPhong stations, the amount of rainfall averages 140 mm/year, is the period of water redundancy from September to October at BauNoi and in July, September and October at HongPhong. The amount of rainfall that can be used as a water source for groundwater recharge is estimated at 140,000 m^3/km^2/year [28,30].

Infiltration at the studied area was calculated using chloride concentration in precipitation (5.32 mg/l) and in anthropogenic uninfluenced groundwater (59.65 mg/l). Since no chloride evaporation occurs in the sand dune, infiltration (R) is calculated based on the mass conservation equation, resulting in:

$$P \times Cl_{precipitation} = R \times Cl_{groundwater}$$

With P: precipitation in the study area

According to the data of BauNoi station with an average precipitation of 760 mm/year, the amount of rainfall, which infiltrates to groundwater, is estimated at 67,900 m^3/km^2/year, while according to the data of HongPhong station with an average precipitation of 815 mm/year, the amount of rainfall, which infiltrates to groundwater, is estimated at 73,000 m^3/km^2/year. Isotope analyses were conducted on 74 water samples at the laboratory of the Institute of Atomic Energy, Vietnam and Geokarst in Trieste, Italy. Tritium data at the wells and in BauNoi suggest that the age of the groundwater is only 20 to 40 years, representing significant localised recharge [1,11,19], even though groundwater is deep over most of the area.

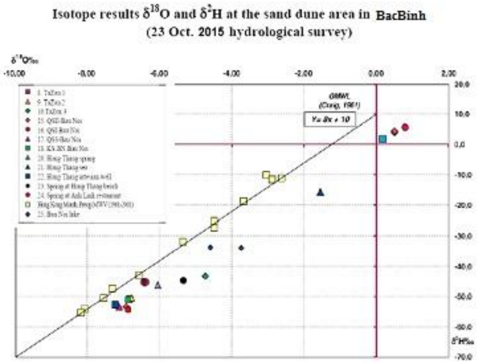

Fig. 6. Isotope results of water's samples taken on October 23, 2015 in Bac Binh

Geophysical study for Aquifer thickness

Modern geophysical methods were used to investigate as well as magnetotellurics sounding for substantially deep structures [22]; Vertical electrical sounding (VES) and Electrical profiling (EP), Magnetic resonance sounding (MRS) and Seismic refraction prospecting (SRP) for shallow structure; Very low-frequency electromagnetic (VLF), Georadar (GPR) for near-surface structures [9,12,14]. The aim of the geophysical investigations is the appraisal of the hydrogeological potential of groundwater augmenting the area. Then two complex geophysical methods are selected for their cost-effectiveness and their proven success:

- The electric resistivity by VES and EP with GPR is used for shallow bedrock (<40 m);
- The electric resistivity by VES, MRS and EP with SRP is used for deep bedrock.

The criterion for geoelectrical interpretation is based on the range of resistivity values for different geological formations types, as we know that the sediment of the study area consists of mainly red sand and white sand. The samples of those materials are collected and measured resistivity and shown in Tab. 1.

Due to the considerably dry sand at the surface of the study area, we should collect geoelectrical data during the rainy season. The hydrogeological structures are investigated in two sub-regions for the potential of groundwater augmenting in studying area:

There are TaZon sub-region (west part of the study area) and BauNoi sub-region (east part of the study area), where the depth to the aquifer is 1-12 m, and the thickness of the aquifer is 20-50 m. The bedrock for those sub-regions is 50-100 m. Groundwater in the aquifers is freshwater because the values of resistivity calculated by geoelectrical data are about 20 Ω.m.

VLF data from profiles are interpreted using filtered techniques and give information regarding the conductive zone down to 40 m on the sub-region BauNoi. This zone is interpreted as water-saturated sand. The GPR data are interpreted using the WinEkkoPro program to delineate the bedrock structure for three profiles. The bedrock profiles are at 10-15 m depth, located

TABLE 1

The range of resistivity for sedimentary materials of studying area

Sedimentary material	Resistivity in [Ωm]
Red dry sand	1500-2500
Red moisturised sand	300-600
Red saturated sand	80-150
White dry sand	1000-1600
White moisturised sand	200-400
White saturated sand	40-100
Moisturised clay	20-40
Saturated clay	10-20

(Source from N.V.Giang, 2006)

around BauThieu mountain. The groundwater for sub-region BauThieu is considerably limited, or there is no aquifer. The most important consideration for successful geophysical application in this kind of dry sand at the surface of the study area is to choose a suitable period for collecting data, i.e. during the rainy season, when good electrical contact can be established for electrical resistivity soundings. The results of geophysical investigation are useful for the hydrogeological structure to groundwater augmenting in the study area and proved by eight monitoring wells with depths from 31.5 to 109 m.

The methods of VES and SRP are considered favourable techniques for assessing groundwater resources in the study area. While VES is currently used in shallow bedrock (<40 m) areas, seismic prospecting is used for deep bedrock estimation. The rainy season is a suitable period for a VES investigation because there is an ideal electrical contact for establishing the electrical resistivity soundings. Fig. 7 is an example of a VES performance (Fig. 7a) comparison compared

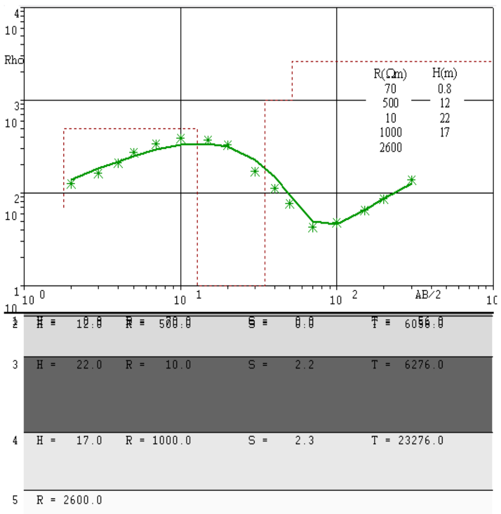

Fig. 7a. Diagram interpretation of VES BauNoi station

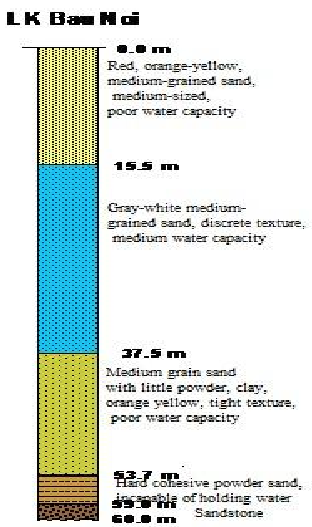

Fig. 7b. Stratigraphic column of borehole KS BauNoi

with the borehole stratigraphic column (Fig. 7b) right next to the measuring point-LK BauNoi. Thus, aquifers have been identified at BauNoi.

Fig. 8 is a cross-section according to the refractive seismic data on a measurement line from BauNoi to BauTrang (3750 m). The boundary line between the structural layers is divided according to the value of the seismic wave propagation velocity. The base rock foundation has a value of greater than 3000 m/s.

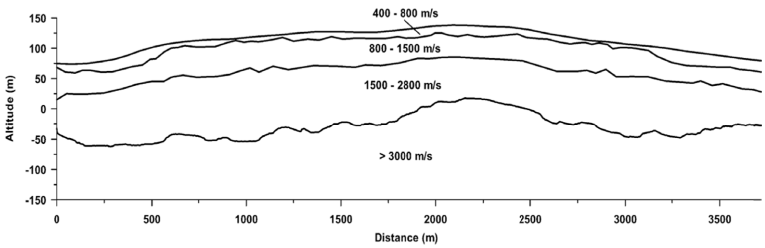

Fig. 8. Cross-section of seismic refraction from BauNoi to BauTrang in the BacBinh area

The interpretation of the seismic data indicates the occurrence of the ryo-dacitic bedrock at depths between 60 and 140 m below ground level and the occurrence in the sand deposits of a potential aquifer of the same thickness. Magnetic resonance sounding (MRS), as a non-invasive geophysical method, has emerged as a new technique for groundwater investigation in BacBinh. The purpose of MRS surveys in the sand dunes area is to discover the character of the aquifers. It was found from the inversion data that an aquifer located between the depths of 44 and 75 m have an ideal water-bearing capacity (water content from 4 to 10%) was confirmed by the well LK1. While, the results of the others MRS measurements showed one aquifer with low water-bearing capacity, which is confirmed by the observations in two wells (Fig. 9).

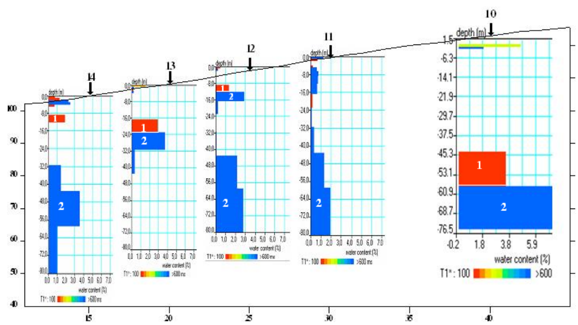

Fig. 9. Results of interpretation for profile T1 by magnetic resonance sounding data in Bac Binh area
(1 – fine sand layer; 2 – coarse sand layer = aquifer)

The synthesis of geophysical survey materials allows us to draw the foundation rock of the entire survey area (Fig. 10), and from that, the depth of the aquifer can be determined and is the basis for the MAR project here.

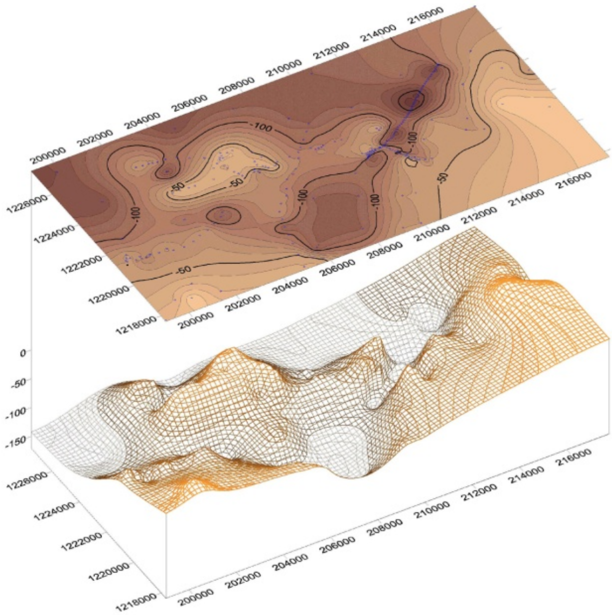

Fig. 10. The distribution of basement (bedrock) for study area by complex of geophysical data

The drilling exploration was carried out for the following: a) confirm the lithostratigraphy and the hydrogeological asset; b) carry out aquifer pumping tests for aquifer hydraulic characteristics determination; c) collect water samples for both chemical, bacteriological and isotopes analyses; d) monitor groundwater levels; e) determine groundwater flow direction and velocity through tracer tests (Rhodamine) [29]. A total of 600 m of drilling were carried out in the research area, including exploratory, observation and exploitation wells. The above investigation's results confirm that the main aquifer is unconfined, having a thickness varying from 33 to 68 m. Groundwater level ranges from ground level to 26 m, with well yield varying from 1.3 to 2.5 l/s. The aquifer is represented by upper-middle Pleistocene and Holocen marine-eolian sediments, consisting of fine to medium loose quartz sands.

4. Aquifer test

BauNoi was chosen as the site for the MAR project (Fig. 11) due to its close proximity to HongPhong village affected by longstanding droughts during the last 20 years.

During the experimental pumping period from May to November 2016, the changes in the concentration of main ions over time at BauNoi lake (Fig. 12) and at the borehole KS BN (Fig. 13) were observed to decrease slightly.

Piper plot of water quality [13,17] shows no significant difference between dry season and rainy season (see Fig. 14).

When analysing the change of bacteria content over time, it was seen that the heat-resistant Coliform and E.Coli concentrations all changed during the pump experiment. However, after

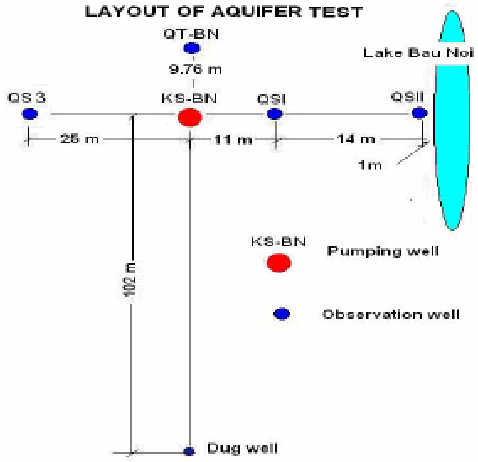

Fig. 11. Well lay-out for aquifer test at BauNoi

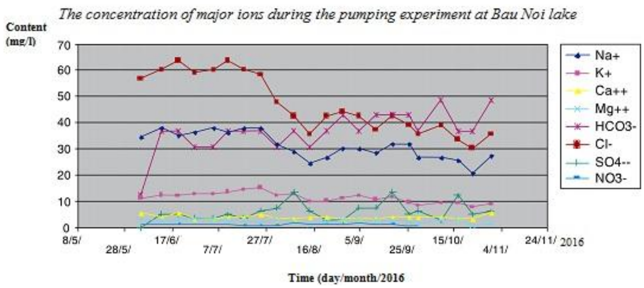

Fig. 12. The change of the concentration of major ions during the pumping experiment at BauNoi lake

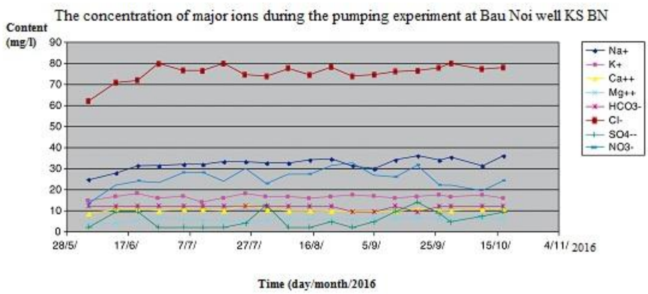

Fig. 13. The change of the concentration of major ions during the pumping experiment at BauNoi well KSBN

the experiments, the concentrations remained stable. At the KS-BN pump well, the amount of E-Coli is always very small or zero. Due to the elevated content of contaminants (Coli bacteria) in the BauNoi groundwater, an aquifer recharge through bank filtration technique was envisaged.

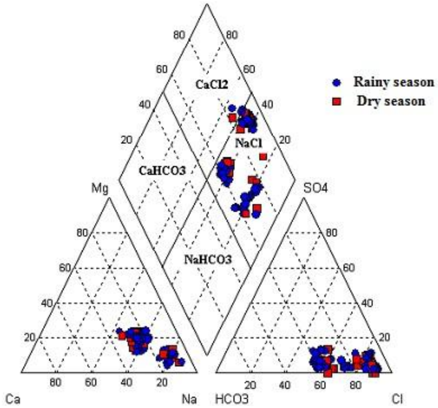

Fig. 14. Piper graph of water quality

An aquifer test according to the well lay-out in Fig. 11 was conducted for 162 days of uninterrupted pumping (constant rate of 2.4 l/s or 207 m^3/day), commencing on 27 May 2016 with the following aims: – To determine hydrogeological parameters of the aquifer (transmissivity, hydraulic conductivity, sustainable yield), to assess the potential of the aquifer for groundwater supply and – To apply managing aquifer recharge through bank filtration techniques and to improve water quality (to remove the high content of E-coli in groundwater). During the aquifer test, 33,600 m^3 of groundwater was abstracted. The drawdown at the end of the test in the pumping well and the observation wells was as follows: KS-BN (pumping well) = 2.8 m; QT-BN = 0.38 m; QSI = 0.24 m; QSII = 0.15 m; QS3 = 0.30 m.

Based on the results of the pumping, the hydrogeological parameters were determined using Thiem-Dupuit, Cooper-Jacob (drawdown-time and drawdown-distance), and Recovery Theis-Jacob methods [27,29] (Tab. 2).

TABLE 2

Transmissivity, hydraulic conductivity and specific yield of the unconfined aquifer

Method	Transmissivity kD (m^2/day)	Hydraulic conductivity k, m/day	Specific storage
Thiem-Dupuit	230	—	
Cooper-Jacob (drawdown-time)	538	13,7	0,170
Cooper-Jacob (drawdown-distance)	235	7,8	0,157
Recovery Theis-Jacob	594	16,5	0,175
Average	399	12,67	0,167

(Source from N.V. Giang and B.T. Vuong, 2016)

The kD and k values for each method in Table 2 are shown as average values of kD and k calculated at each well. Two Rhodamine tests [19] were carried out in 2 observation wells located on the well axis and down gradient to the production well. The Rhodamine WT test was carried out from 1 June 2016 until 14 July 2016 (44 days) during the pumping operation and consisted in injecting a solution composed of 100 mg of Rhodamine (C28H31N2O3Cl) in 20 litres of water in

QT-BN observation well and detecting the arrival time of the same solution in the pumped well KS-BN, at a distance of 10 m. The mean transit time to the well resulted in a concentration peak of the solution at 22.43 days, with a velocity of 44.6 cm/day. The second Rhodamine test has been carried out in a direction perpendicular to the groundwater flow (natural groundwater flow in BauNoi is from N to S), such as between the pumped well and the monitoring well QSI, located 11 m downgradient, south of the pumped well. The result shows that the tracer cloud came into the pumping well at 26.5 days after injection. Tracer concentrations are lower, from 0 to 1.1 ppb. The transit time of the tracer cloud was calculated using the above equation as 62.16 days, and the mean velocity of water moving between two of these wells is 17.70 cm/day (Fig. 15).

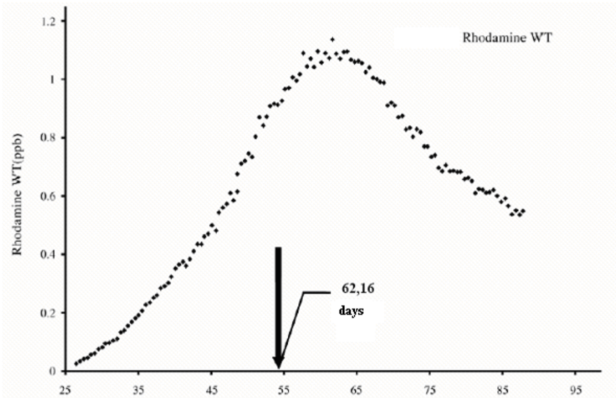

Fig. 15. Variation of Rhodamine WT concentration in well KS-BN vs. time following release in observation well QT-BN at Bau Noi (parallel to ambient groundwater gradient but moving in upgradient direction towards the pumping well)

The groundwater flow velocity is 44.6 cm/day and 17.70 cm/day, respectively. Water samples for chemical and microbiological analyses were taken weekly and showed that the nitrates (NO3), and the coli bacteria in the water, decreased with time of pumping. Therefore, the bank filtration technique gave very satisfactory results in terms of water quality improvement.

Fig. 16. Water from the pumping test had (left) and the cattle pond (right)

The pumped water was conveyed through a 3 inches pipe to a cattle pond (Fig. 16), constructed within the project and located some 600 m away to the north of the pumped well at an elevation of 52 m higher than the well's elevation. The resulting head loss from the elevation difference affects the pump yield and stabilises at approximately 2.5 l/s. The entire area of BauNoi has also been fenced to avoid cattle continuing polluting the groundwater.

5. Groundwater modelling and monitoring

Groundwater monitoring is an indispensable part of the development of a MAR project. Information from monitoring is essential to plan the quantity and quality of recharge and recovered water. Information from monitoring is also used to evaluate the effectiveness of MAR and to estimate the volume of water to be recharged and recovered or to ensure adequate residence time of recharged water in the aquifer for necessary water quality improvements, such as inactivation of pathogenic viruses and bacteria before use of water for drinking supplies [20]. Groundwater monitoring was conducted by automatic transducers/data loggers for electrical conductivity, temperature and water level (CTD divers) in wells and surface water in BauNoi [29]. The plots of the groundwater level and electrical conductivity of the groundwater versus the time of these wells and BauNoi are shown in Fig. 17 and Fig. 18.

The Groundwater Modelling System – GMS, version 3.1 was used to forecast the impacts of proposed groundwater abstraction plans and the effectiveness of managed aquifer recharge. The study area has an area of 927 km^2, and the groundwater system was simulated as a two-layer system. The first layer represents the unconfined intergranular aquifer, having a horizontal hydraulic conductivity, k, of 12,67 m/day; a porosity, n, of 0.36; a specific yield, Sy, of 0,167, vertical hydraulic conductivity is 1/10 of the horizontal hydraulic conductivity. The second layer represents the weathered zone and bedrock, which is considered as an aquitard, having hydraulic conductivity of 10-4 m/day. Results of the steady-state model show that the groundwater potential reserves of the area are 230,000 m^3/day, and the safe amount of groundwater abstraction is 138,000 m^3/day, amounts that can be considered average for many years. During the dry season

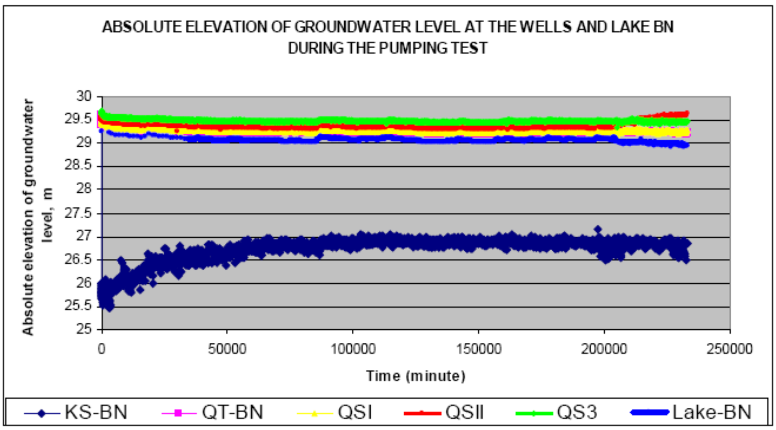

Fig. 17. Groundwater level during a pumping test in wells and lake Bau Noi

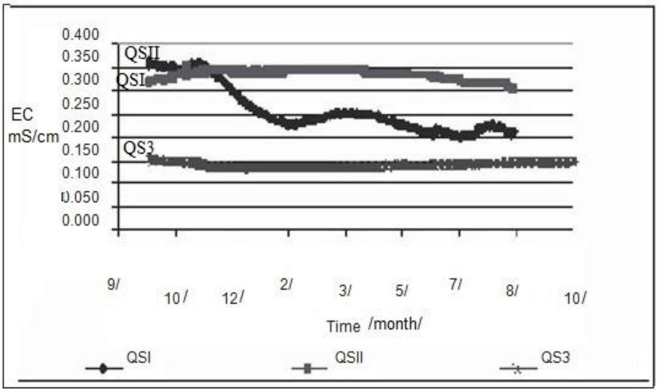

Fig. 18. Changes in groundwater electrical conductivity versus time

(December to March), the unsteady state model shows that the groundwater potential reserve is 110,000 m^3/day, and the safe reserve is 43,000 m^3/day. These numbers are considered the minimum amounts of groundwater potential and safe reserves. The unsteady-state model shows that, in the rainy season, the groundwater potential reserves and the safety reserves are 470,000 m^3/day and 201,000 m^3/day, respectively [29]. These numbers are considered as maximum amounts of groundwater potential and safety reserves.

6. Conclusions

The research area is located in the BacBinh district, BinhThuan Province, the coastal plain in Central Vietnam. Due to an uneven rainfall distribution and a four months period (from December to March) characterised by very little precipitation, the area suffered considerable water shortage during the dry season.

Extensive geophysical, hydrological and isotopic investigations, including drilling campaigns, long term pumping tests and continuous monitoring of groundwater levels in 4 monitoring wells, show that the sand dunes formation is characterised by the occurrence of an unconfined porous aquifer, of variable thickness (40 to 60 m), with a water table emerging at ground level in depressed morphological areas (20 to 30 m a.s.l.).

A 162 days pumping test carried out in this site proved that using the bank filtration technique has considerably improved water quality, which was previously highly contaminated by E-coli bacteria. The well's field that was developed within the current project is now capable of supplying 220 m^3/day of substantial water quality to the HongPhong community (more than 2500 residents live), which was recurrently affected by severe droughts.

The pumping tests and observations of an experimental bank infiltration in the sand dune area of BacBinh can be used as a model for other parts of the Country.

The results of the study also showed that the growing water demands due to agricultural, domestic and touristic supply could in the long term affect the quality of the existing groundwater resources if massive exploitation occurs, therefore determining the irreversible process of saline intrusion in the coastal areas and that high chloride contents in groundwater.

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