Introduction and objective:
High concentration of arsenic is reported from deep groundwater of Northern Chianan Plain aquifer of Taiwan (Guo et al., 1994; Liu et al., 2006). In search of arsenic clean water, extensive researches, since last decade, were carried out to understand the source of arsenic and its mechanism of mobilisation (Liu et al., 2005; Jang et al., 2006, Nath et al., 2008). However, in absence of detailed sedimentological, geochemical and hydrological studies, raging debates still exist about the sources of arsenic, mechanism of its release from aquifer sediments and moreover the spatial distribution of polluted wells in Chianan plain aquifers. For example, on the basis of stable isotope and groundwater geochemical data, a recent study (Nath et al., 2008) speculated a considerable fraction of groundwater arsenic could be contributed by mud volcanoes and geothermal springs located on central mountain range, east of Chianan Plain. Preliminary stable isotope data of groundwaters in Chianan Plain and water level data in the monitoring wells of Taiwan Groundwater Monitoring Network (TGMP) also indicated a westward flow from central mountain to south west coast (Lu et al., 2008) and thus raise the possibility of recharge from those sources to Chianan Plain aquifer. Assuming a considerable recharge from those sources mentioned above, one would expect a gradual decrease in arsenic concentration from east to the western part of the aquifer. However, limited data from the eastern foothill area adjacent to central mountain however do not show any significant concentration of arsenic in groundwater and thus pose a reservation to earlier speculation. Moreover, enriched stable isotopes values and high concentrations of major ions reported in their study could indicate the intrusion of saline water in those coastal aquifers in stead of recharge from mud volcano and geothermal springs. Careful and strategic sampling along various E-W profiles and study the aquifer chemistry of entire Chianan Plain in conjunction with water from volcanic and geothermal sources could have resolved this debate. However, very few studies have addressed this issue till date.

Notably, to address the arsenic pollution problem, most of the previous workers limited their detailed geochemical and hydrological studies in a small SW coastal part of Chianan Plain aquifer where ‘blackfoot disease’ was detected in local inhabitants. As mentioned earlier, similar detailed studies are rarely reported from other parts of the Chianan Plain. Some sporadic works, however, show that most of wells are unpolluted outside the ‘blackfoot disease’ area. This observation, therefore, leaves some queries- (a) why concentration of arsenic is different in those two areas? (b) are those groundwater geochemically different? If so, why? (c) are distribution of arsenic and organic matters different in those two areas? (d) is arsenic in groundwater flushed out from the central and foothills part of the plain to the coastal part? To address these queries, the present works proposes close and systematic collection of water samples along various E-W profiles of Chianan Plain and detail geochemical and stable isotope study of those water samples.

Work Plan:
The candidate collected groundwater samples along some selected profiles for major ions and stable isotope study. In addition to sample collection, the candidate proposed to measure the groundwater level during pre and post monsoon time. He also took help from website of water resources agency of Taiwan for groundwater level data for making contour diagram and generalized groundwater flow diagram. Apart from studying groundwater-volcano fluid interaction, groundwater geochemical data are applied to understand the variation of redox state along different transects from mud volcano to Chianan Plain aquifer. Fence diagram are constructed with available lithology data to understand the subsurface sediment packages and tectonic features around the observation and sample collection wells. Together with flow model, fence diagram, geochemical and isotope data, the candidate would quantify the impact of mud volcano by simple mass balance technique.
Apart from geochemical studies, 12 wells from various parts of Chianan Plain were sampled for determination of $^3$H concentration to understand the recharge rate as well as flushing history of the aquifer.

**Methodology:**
After prolong purging the groundwater samples are collected in 30ml and 100 ml double capped plastic bottles from 53 bore wells, 5 surface water bodies and 5 mud-volcanoes for stable isotope and other major ion studies respectively. pH, EC, TDS, Salinity, ORP and temperature of the samples are measured in the field. Samples collected for cation analysis are acidified in the field. All samples are preserved in a cold and dark place before major ion, trace element and stable isotope analysis. Stable isotope (O and H) ratio of all water samples are measured in a dual inlet isotope ratio mass spectrometer at Academia Sinica under the joint collaboration with Prof. Wang. Cationic and anionic concentration of well water were measured in ion chromatograph. Concentration of trace elements was measured in National Chung Cheng University, Chiayi under the joint collaboration with Prof. Lu at Department of Earth and Environmental Sciences. Flow and fence diagram would be constructed using Surfer and WinFence software. $^3$H concentrations are measured in ATOMKI at Hungary in joint collaboration with Dr Laszlo Pacsu.

**Results.**
Results and preliminary findings are briefly given below. Groundwater samples are collected from 50 locations shown in Fig 1a. Location of observation wells are shown in Fig. 1b. Water level data were collected from Central Groundwater Agency. Fig 1c shows the distribution of arsenic concentration in the sampled wells. As observed in Fig 1a, we classify the water samples into three different groups on the basis of their proximity to central mountain, TDS and conductivity value. Hence, in discussion, we will refer them as proximal (near to central to central mountain), central and distal (or coastal) water samples.

Considerable differences are observed among the trends of major ions in proximal, central and distal samples. Distal samples show wide range of Na and Cl concentration and proximal samples show smallest range of variation among those ionic concentrations (Fig-2). Large variation of distal samples possibly indicates intrusion of various proportion of saline water into different parts of aquifer. On the other hand low concentration of Na and Cl in proximal samples indicates either low water rock interaction or most of the dissolved Na and Cl are flushed out to the proximal and distal part of the aquifer.

Proximal water samples show small range of Ca and HCO$_3^{-}$ concentration but those two ions show significant correlation. This indicates dissolution of carbonate minerals in the proximal aquifer and subsequent flushing to the central and distal parts. On the other hand excepting Nanho, all other central groundwater samples show wide range of Ca and HCO$_3^{-}$ and reasonably good correlations between the ions ($R^2=0.64$). This indicates carbonate dissolution mainly controls the groundwater geochemistry in the central part but flushing is relatively low compared to the proximal part. Poor correlation between those ions in the distal part
indicates sources of Ca other than carbonates in aquifer sediments possibly from sea water.

Fig. 3. Ca-HCO₃ scatter diagram in distal, central and proximal samples.

Stable isotope cross plots show significant evaporative enrichment in distal groundwater as evident by the slope of local meteoric water line lower than that of Global Meteoric water line (~8). Highest slope and good correlation between two isotopes indicate proximal water mainly indicates pristine precipitation and the range possibly indicates seasonal variation of precipitation isotopes.

Fig. 4. 6D-δ¹⁸O scatter diagram in distal, central and proximal samples.

As evident from Fig 1c, apart from the groundwater of distal/coastal part, few groundwater samples collected from central part of the aquifer show alarmingly high arsenic concentration like Sinshih (667 ppb), Soji (171.6 ppb), Chintanlao (144 ppb), Dongshan (249 ppb) and Beigang (248 ppb). This localized high concentration could be resulted due to a) difference in sediment arsenic concentration, b) difference in local redox situation, © different flushing rates along various E-W profiles.

Fig. 5. As-Fe scatter diagram in distal, central and proximal samples.

Fig. 6. As-Mn scatter diagram in distal, central and proximal samples.

However, due to paucity of drilled cores and detail sediment geochemistry of Chianan plain, first possibility can not be verified in proper local scales. However, sequential leaching experiments carried out on sediments from two cores (one at Tainan, near coast and Hsinying at central Chianan plain show similar arsenic content. Detail sediment geochemistry data of Choushui river plain, adjacent to Chianan plain also shows no significant variation in arsenic content across the aquifer. On the other hand Fig 5 and Fig 6 show no significant correlation among the redox sensitive tracers (Fe and Mn) with As concentration in proximal, distal and central part of the aquifer.

In the distal part high arsenic groundwater generally show low Fe concentrations possibly indicating reprecipitation of
Fe rich sediments after microbial reduction. However in the central part some arsenic rich groundwater still show considerably high iron concentration. Proximal groundwater are however free from arsenic.

Major findings.

1. Present study identifies a number of arsenic rich pockets apart from blackfoot disease area, even some of them are close to central mountain. Shallow groundwaters are extensively used for pisciculture in the distal/coastal part and for agriculture in central and proximal part. This study shows detailed geochemistry of subsurface sediments are extremely required in central and proximal parts of the aquifer.

2. Poor correlation between arsenic and other redox sensitive ions indicate re-adsorption of arsenic in partially reduced sediments and co precipitation of Fe- and Mn- bearing phases. These chemical processes are fairly common in other arsenic- polluted area with identical fluviodeltaic depositional environment.

3. Low TDS, conductivity and concentration of all major ions in proximal water indicate two possibilities-a) recharged fresh water has small residence time in proximal part of the aquifer which does not allow sufficient water rock interaction or b) since deposition of aquifer sediments, this part of the aquifer suffered extensive flushing due to high hydraulic gradient, so all ions are possibly flushed out to the central and distal part of the aquifer. 3H data of groundwater samples, which is not presently available, would give some idea of the residence time.

4. It is evident from various sediment profiles that aquifers are isolated within the clay layer in some part of Chianan Plain. Even the aquifers are also isolated in many places near foothills area where aquifers are supposed to be coarse grained and highly conductive, as mentioned by previous workers. Residence time of water in those isolated aquifers is therefore considerably large and thus allows prolonged water rock interaction and subsequent release of arsenic in groundwater although the local hydraulic gradient is considerably high.

5. Major ion chemistry of groundwater shows dissolution of carbonate mineral is the most dominant chemical processes occurring in the aquifer. However aqueous chemistry is substantially modified in the coastal/ distal part due to intrusion of saline water.

Future work:

(1) To understand the flow velocities along different E-W profiles groundwater samples collected from proximal and central part of the aquifer are being analyzed for $^3$H concentration.

(2) Due to paucity of sediment chemistry data. DOC, DO data from larger part of Chianan plain aquifer will be compiled to understand the local variation of redox condition.

(3) Water level contours will be constructed for pre and post monsoon time to understand the variation of hydraulic gradient in different sessions and different part of the study area. That will indicate the amount of flushing of groundwater throughout the year.

(4) Available lithology data will be compiled in form of fence diagram to understand the lateral continuity of different of different aquifers.

(5) One manuscript is being prepared from this work.

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二、研究或教學或科技研發與管理成效評估（由計畫主持人或單位主管填寫）

Please evaluate the performance of research, teaching or science and technology R&D and management work: (To be completed by Project Investigator or Head of Department/Center)

(1) 是否達到延攬預期目標？
Has the expected goal of recruitment been achieved?
Ans: Yes, the expected goal of recruitment has been achieved.

(2) 研究或教學或科技研發與管理的方法、專業知識及進度如何？
What are the methods, professional knowledge, and progress of the research, teaching, or R&D and management work?
Ans: The employee has proficient professional knowledge and utilized a novel method to achieve the expected goal.

(3) 受延攬人之研究或教學或科技研發與管理成果對該計畫（或貴單位）助益如何？
How have the research, teaching, or R&D and management results of the employed person given benefit to the project (or your unit)?
Ans: The results produced by the employee are beneficial to this project and to the employer's laboratory.

(4) 受延攬人於補助期間對貴單位或國內相關學術科技領域助益如何？
How has the employed person, during his or her term of employment, benefited your unit or the relevant domestic academic field?
Ans: The results produced by the employee have provided significant contribution to the arsenic research in Taiwan.

(5) 具體工作績效或研究或教學或科技研發與管理成果：
Please describe the specific work performance, or the results of research, teaching, or R&D and management work:
Ans: The employee worked hard and produced good results that can be published in good journals.

(6) 是否續聘受聘人？Will you continue hiring the employed person? □續聘 Yes ■不續聘 No, the employee got a permanent job in India.

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